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Controlling Coastal Sand Dunes in the Pacific Northwest

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and
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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C., SEPTEMBER 1942

FOREWORD

SIX years ago the advancing sand dunes on the Clatsop Plains of Oregon, at the mouth of the Columbia River, were menacing forts, military reservations, roads, and private property valued at $22,000,000. Worse, they were also threatening to impede the flow of nearly $300,000,000 of ocean-going commerce moving in and out of the entrance to the Columbia River, which lay directly in the path of the oncoming dunes.

Today the sand movement on the Clatsop Plains has been arrested, and what was once a dangerous expanse of wind-blown sand 20 miles long and at places 1½ miles wide has been transformed into a mantle of planted grass.

In wartime this work is especially vital, much more important than the money values that were protected by this 6-year job of the Soil Conservation Service.

Similar conditions are found at the mouths of other navigable rivers on the Pacific coast and on other coastal areas. The methods and techniques of dune control described in this publication, as applied to the Pacific Northwest coast, can be adopted as well to other threatened points.

The effective control of the coastal dunes has been accomplished by the careful application of a few fundamental scientific principles. Some of these are refinements of recognized methods, whereas others are the direct result of the cooperative observational studies of nursery and other operations of the Soil Conservation Service on the Clatsop Plains. The methods and materials that were used are carefully described herein. They can be applied to most coastal dune areas with only slight modifications, and they are likewise effective in the correction of inland dune areas.

H. H. BENNETT,
Chief, Soil Conservation Service.

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Controlling Coastal Sand Dunes in the Pacific Northwest

By Willard T. McLaughlin, *assistant soil conservationist*, and Robert L. Brown, *assistant forester, Nursery Division, Soil Conservation Service*

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INTRODUCTION[1]

Extent and Location of Dunes

AREAS of unstable dune sand occur in the United States along the coasts of the Atlantic and Pacific Oceans, the Gulf of Mexico, and the shores of the Great Lakes. Inland dune areas of recent origin occur throughout the Great Plains in New Mexico, Colorado, Texas, Kansas, Wyoming, North Dakota, and South Dakota.[2] Inland dune areas occur in other portions of the Western States and are common in small areas along the larger rivers in the Pacific Northwest.

On the Pacific coast, dunes and sandy spits occur locally from Baja California to southern Alaska. Dune areas total more than 50,000 acres of the Oregon coast and are usually associated with the larger streams and rivers, in many instances as sandspits. The most extensive area extends from Heceta Head southward to Coos Bay, a distance of 60 miles. Dune areas also occur at Bandon and in southern Coos and northern Curry Counties southward to Blacklock Point. The Clatsop Plains dune area in Oregon extends from the mouth of the Columbia River southward to Tillamook Head, a distance of 20 miles. Minor dune areas are situated at Tillamook Bay, Netarts Bay, Sand Lake, and the mouths of the Nehalem, Nestucca, Yaquina, Alsea, and Rogue Rivers. In the State of Washington, coastal dune areas occur at Grays Harbor, Willapa Bay southward to the mouth of the Columbia River, and at other locations, and total about 5,000 acres.

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[1] The authors wish to express appreciation for helpful suggestions on dune-control technique and for guidance throughout the control program to A. L. Hafenrichter, senior agronomist, Soil Conservation Service, U. S. Department of Agriculture, and to H. A. Schoth, agronomist, Bureau of Plant Industry, United States Department of Agriculture, for assisting with the preparation of the manuscript.

[2] Whitfield, C. J., and Perrin, J. A. sand-dune reclamation in the southern great plains. U. S. Dept. Agr. Farmers' Bul. 1825, 12 pp., illus. 1939.

NEED FOR CONTROL

Coastal dune areas tend to increase in size and, if uncontrolled, become destructive to adjacent valuable property. In the vicinity of Coos Bay the dunes have attained a height in excess of 100 feet. At several points the dunes are advancing onto forests and burying them, overriding valuable pasture and croplands, obliterating lakes, threatening military reserves, filling stream channels, and endangering resort property (fig. 1). In the Clatsop Plains dune area many homes and a hotel have been buried or undermined.

The choking of navigable rivers with sand (fig. 2), necessitates expensive dredging. On smaller streams, such as the Siltcoos, Tahkenitch, and Nestucca Rivers, sand has caused shoals that threaten the normal migration of fish. At several points in Oregon, particularly between Coos Bay and Florence, huge dunes are approaching within a few yards of the Coast Highway. The Reedsport water supply at Clear Lake is threatened by great active dunes. Coastal railroads are continually menaced by encroaching dunes.

The experience of landowners along the north Pacific coast, in Europe, and elsewhere, teaches that dune areas are potential threats that may extend for long distances inland and may parallel the coast for many miles. Small "blow-outs," varying in extent from a few square yards to several acres, are often the inconspicuous forerunners of large, active sand areas, unless immediately controlled.

HISTORY OF CONTROL IN THE PACIFIC NORTHWEST

Between 1910 and 1916, 47 acres of trees and shrubs, together with some European beachgrass, *Ammophila arenaria* (L.) Link., were planted on the dune area between Florence and Coos Bay under the direction of the United States Forest Service.

From 1926 to 1928 the Bureau of Plant Industry of the United States Department of Agriculture, cooperating with the Navy and Commerce Departments, supervised planting of European beachgrass and some trees and shrubs including willow, *Salix* sp., and cluster pine, *Pinus pinaster* Ait., on the spit surrounding the Naval Radio Compass Station across Coos Bay from Empire, Oreg.

In 1934, 35.5 acres of European beachgrass were planted in the Siuslaw National Forest, approximately 15 miles south of Reedsport, Oreg. Twenty-five thousand cluster pines also were planted on an area of 26.8 acres. During the following winter and spring an additional 43 acres were planted to beachgrass. Thirty acres of beachgrass were planted west of Clear Lake, the Reedsport water supply, in 1933 and 1934. Some trees were also included with the grass plantings. Approximately 40 acres of dunes were planted in 1936 to beachgrass at Mercer Lake Recreation Camp, just north of Florence, Oreg., where the dunes were encroaching on the timber and camp.

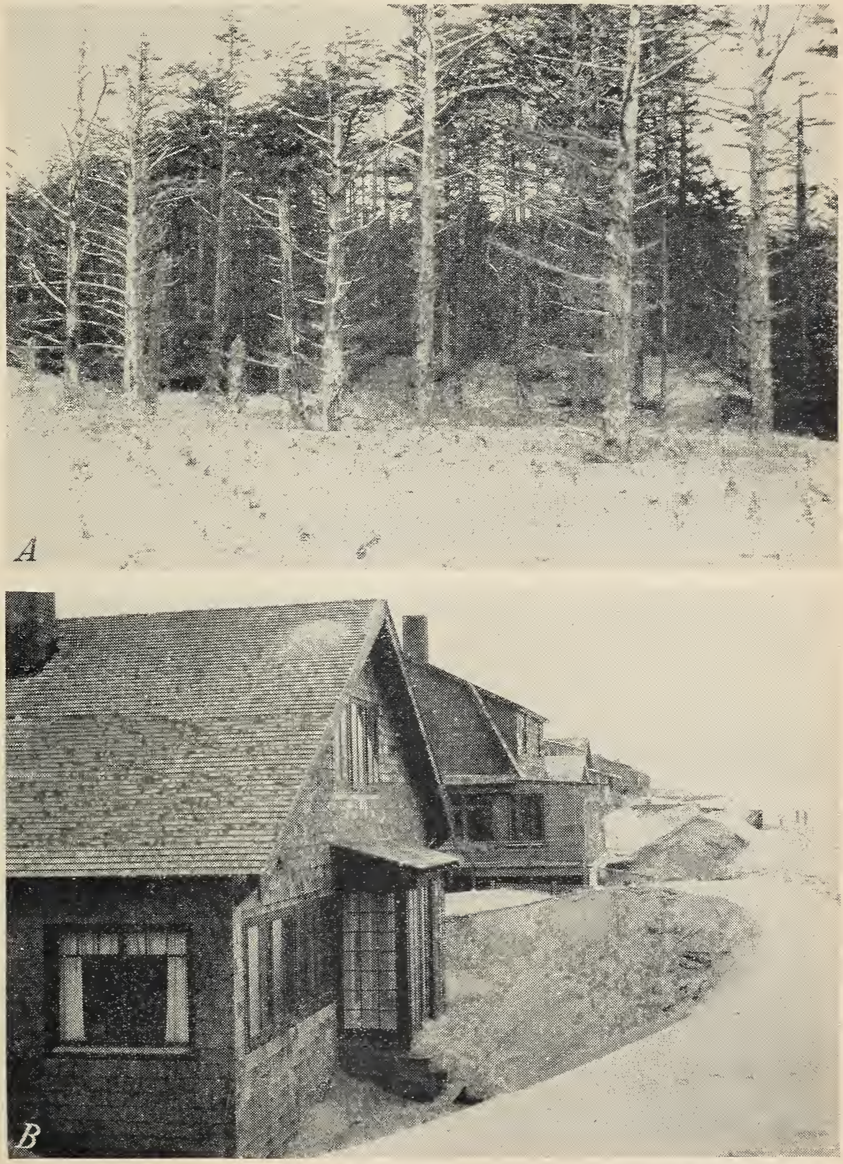

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Figure 1.—Uncontrolled dune sand migrating inland on the Clatsop Plains dune area and destroying, *A*, a Sitka spruce forest and, *B*, valuable homes.

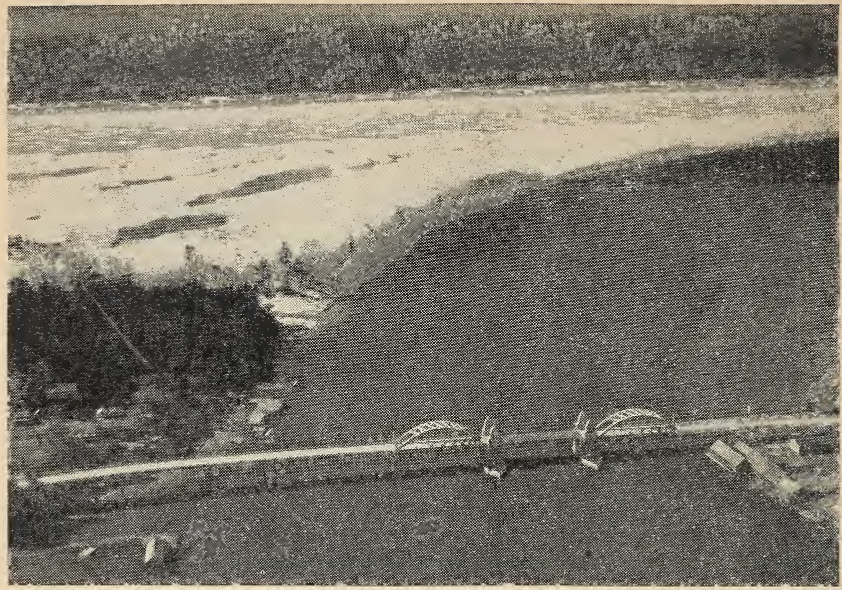

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Figure 2.—A formerly navigable river has been choked by sand sweeping across the spit at the left. This sandy waste moved into and partly buried a forest. The steep sand slope just beyond the trees sloughs into the river and forms shoals or is carried oceanward and washed back onto the beach again.

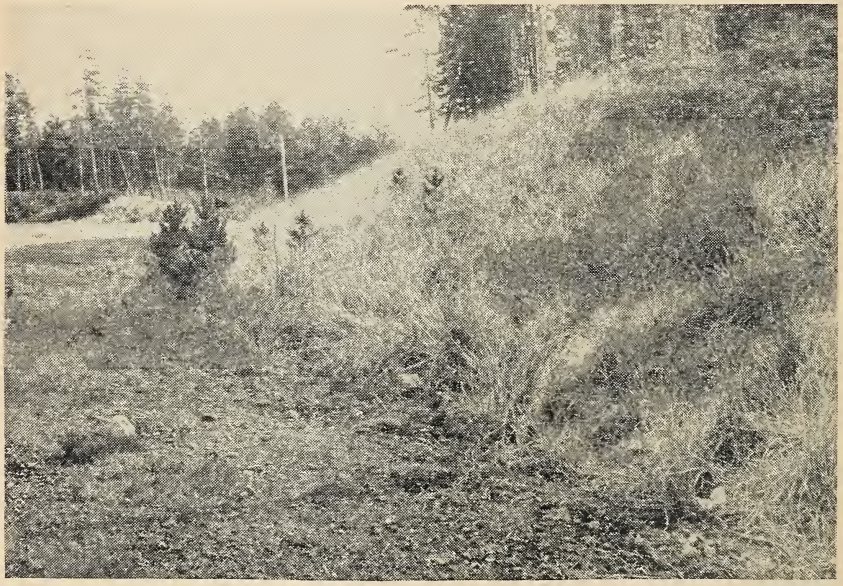

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Figure 3.—European beachgrass planted on a highway cut through sand is an effective protection against wind erosion on the exposed surface.

The Oregon State Highway Commission, during the last several years, has planted many sandy road cuts and fills between Lake Tahkenitch and Newport to European beachgrass (fig. 3) and to shrubs to keep the sand, exposed by the cuts, from scouring and developing blow-outs. Plantings to hold the encroaching sand also have been made along the Coos Bay branch of the Southern Pacific Railroad. Individual property owners at various points along the coast have made small plantings to protect farm and resort property.

A control project, one of the most complete and extensive operations in the western United States, was established by the Soil Conservation Service in the Clatsop Plains dune area of Oregon in 1935, where 3,000 acres of shifting sand were progressively stabilized. In this program the Service had the aid of a Civilian Conservation Corps camp situated at Warrenton. To a considerable extent, the recommendations in this bulletin were derived from this background of successful experience, supplemented by studies and observations of dune-control work in other parts of the country. Largely on the basis of effective results obtained on the Clatsop Plains control project, landowners in the area organized a soil conservation district to maintain and extend the control measures. Two other soil conservation districts also have been formed in nearby coastal areas to attack dune and other land use problems cooperatively on the foundation of local initiative and local responsibility.

The large areas of shifting sand, involving hundreds or even thousands of acres, present a formidable problem of control. It is now recognized that these areas can be controlled only by stringent and extensive methods. The small scouring area or blow-outs often can, however, be healed permanently by the proper inexpensive control practices. An understanding of the forces involved and the means of preventing destruction of land and property by dune sand is essential to attaining efficient control in either large or small areas. This publication is intended primarily to supply information on materials and procedures necessary for permanent control of shifting coastal sand dunes.

CAUSES OF COASTAL DUNES

Natural Dune-Building Processes

Coastwise currents take sand from the rivers where they enter the ocean and from eroding headlands and deposit it on beaches in indentations of the coast. At low tide the surface layer of sand dries quickly, is caught by the wind, and is carried inland. There is nearly always some wind, stilled at times to a breeze of low velocity, at other times approaching hurricane force. It is not always in the same direction, but on the north Pacific coast the prevailing winds are landward. For example, the prevailing summer wind on the Clatsop Plains dune area is north to northwesterly, and the average velocity is approximately 13 miles per hour. Maximum velocities during this period seldom exceed 40 miles per hour. With the approach of winter the prevailing wind shifts to a southerly direction with an average hourly velocity of 16 miles per hour. Gales with velocities in excess of 55 miles per hour occur occasionally, and a few storm winds attain velocities of 85 to 90 miles per hour. These high-velocity winds, especially, move enormous quantities of sand inland.

Beachgrass and other plants, pioneers in the stabilization of sand, advance on the beach to the normal storm tide line, where their encroachment is halted by wave action. These plants decrease the velocity of the surface wind, and sand is deposited in the vegetation.

As the greater part of the sand movement along the north Pacific coast takes place during the high-velocity storms of the winter season, it is during this period that the sand engulfs the vegetation within the zone of deposition. During the spring and summer the vegetation grows up through the sand and forms a lush growth. This is covered again the following winter, and a continuous sand ridge, built layer by layer and extending without interruption parallel to the coast line, results. This is the foredune. This phenomenon is illustrated in figure 4. The lands lying to the leeward of the foredune are protected effectively from the scouring action of the sand-laden wind, and a dense sod or forest cover develops.

If sand is deposited more rapidly than it is blown inland, the beach line will build oceanward, the vegetation will advance to the new storm tide line, and a new foredune will be formed oceanward from the old foredune. This is illustrated in figure 4. The incoming sand will now be deposited on the new foredune, and the old foredune will become occupied by a type of vegetation better suited to these stable conditions. The litter from this vegetal cover will, in time, form a layer of organic material, which will become incorporated with the surface layer of sand. Thus, in time, the sand may support a forage cover; have on it a stand of timber; or, under careful cultivation, provide soil for certain specialty crops.

On the Clatsop Plains dune area a remarkable series of parallel dune ridges with intervening troughs extends for miles from the mouth of the Columbia River southward to Tillamook Head. This series of dune ridges extends approximately 1½ miles inland. These ridges were formed as littoral dunes when the beach was farther east, and as it gradually built oceanward, owing to continual deposition of sand, new foredunes were built and are still being built.

The older dunes lying to the east of the present littoral dune are covered with a heavy sod. Still farther east a spruce-hemlock forest has developed on the dunes.

The normal dune-building and stabilizing process can easily be disrupted, however, by the disturbance of the vegetal cover. The moment the vegetation is thinned and the sand exposed, the wind begins scouring. It picks up the sand and deposits it again where vegetation or some artificial barrier decreases its velocity and carrying capacity. This may be the beginning of a blow-out. From such an insignificant beginning, an active dune area may develop. Any agency that destroys the vegetal cover furthers the development of active dunes. Meandering dunes may move for long distances over a flat plain before they are finally dissipated (fig. 5). The volume of material incorporated in these dunes appears to be determined by the location of a layer resistant to wind erosion. On the low-lying coastal dunes of the Pacific Northwest, it is the summer water table.

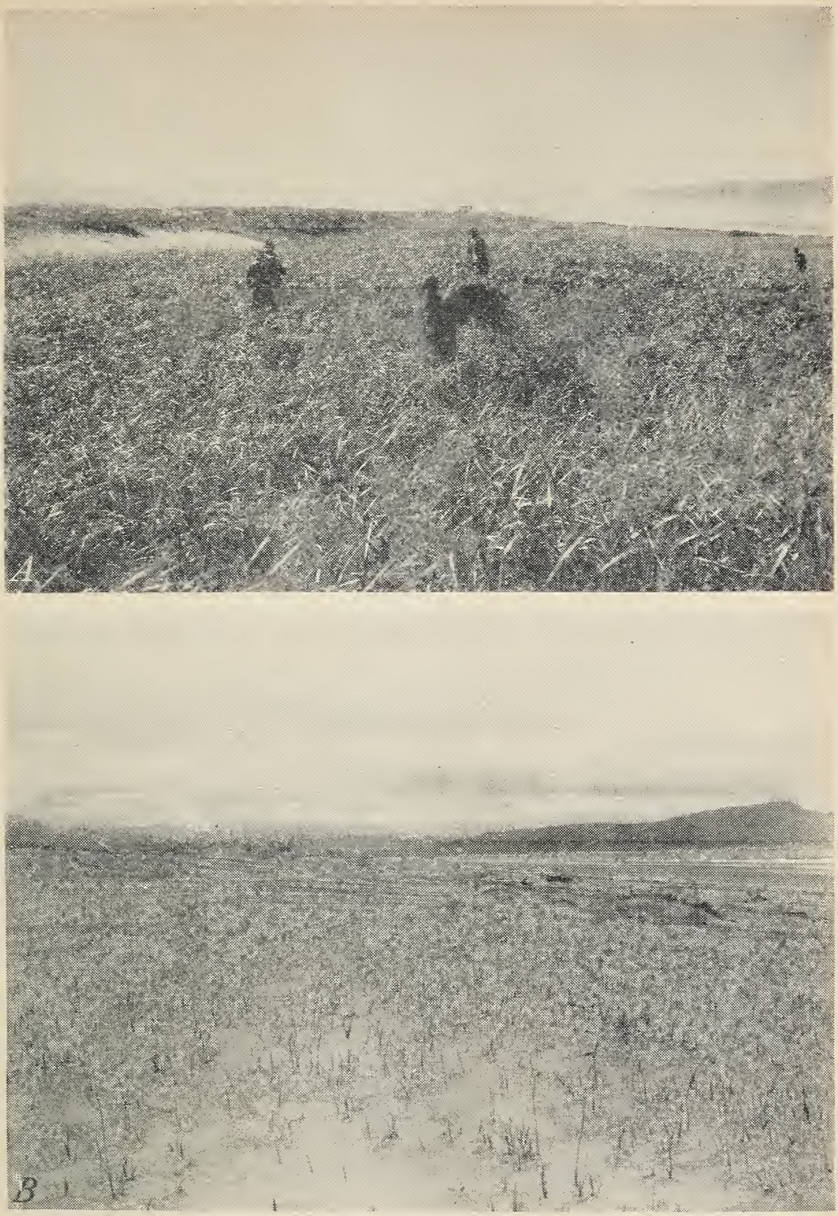

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Figure 4.—A foredune has been built up on the Clatsop Plains dune area as sand from the beach has deposited in the cover of American dunegrass. *A*, The foredune as it looks in summer; *B*, the foredune in winter, when a foot or more of sand has been deposited in the grass. An old foredune is seen at the left.

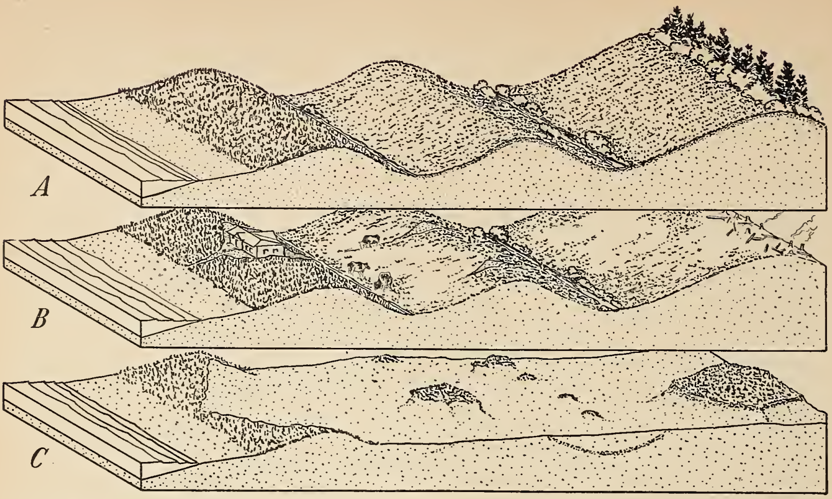

FIGURE 5.—The causes of the development of active dunes on stabilized sandy soils in the Pacific Northwest. *A*, Under normal undisturbed conditions sand from the beach, blown inland by the prevailing winds is stopped at the foredune. Back areas are protected from sand; *B*, forest fires, overgrazing and trailing by livestock, construction, and other disturbances of the surface, break the sod cover. The top, black sand layer containing humus is destroyed, and the wind scours out the underlying gray sand to form blow-outs; *C*, a sandy wasteland results, and as the soil of agricultural value is destroyed or covered, the land is of little economic value. Restoration of such an area involves a slow, laborious process.

FIRE AS A CAUSE OF ACTIVE DUNES

Fire, the red menace of forest and prairie, takes its place among the causes of large areas of active sand dunes, both coastal and inland. The removal of the forest or sod cover on sandy soils not only results in the exposure of the sand directly to the wind but also usually destroys the humus that has accumulated from hundreds of years of plant growth. This humus forms the layer of "black sand" that overlies the gray dune sand, as in the Clatsop Plains dune area, and makes these lands valuable for agricultural or forest purposes. Once the humus is destroyed or is covered by incoming gray sand, the economic value of the land largely is lost. In the vicinity of Florence, Oreg., and in the coastal flat southward to Coos Bay, occasional openings occur within the forests where fires have destroyed the cover. The destruction of the timber has resulted in the development of active dunes; charred stumps remain as evidence of the cause (fig. 6). Destruction of grass by fire has the same effect as the destruction of forest cover. It is vitally important to protect stabilized sand areas from fire.

GRAZING AS A CAUSE OF ACTIVE DUNES

Grazing by livestock has caused formerly luxuriant grass stands to disappear and the sandy soil to blow inland, inundating lakes, pasture lands, and resorts. This is particularly true in the Clatsop Plains

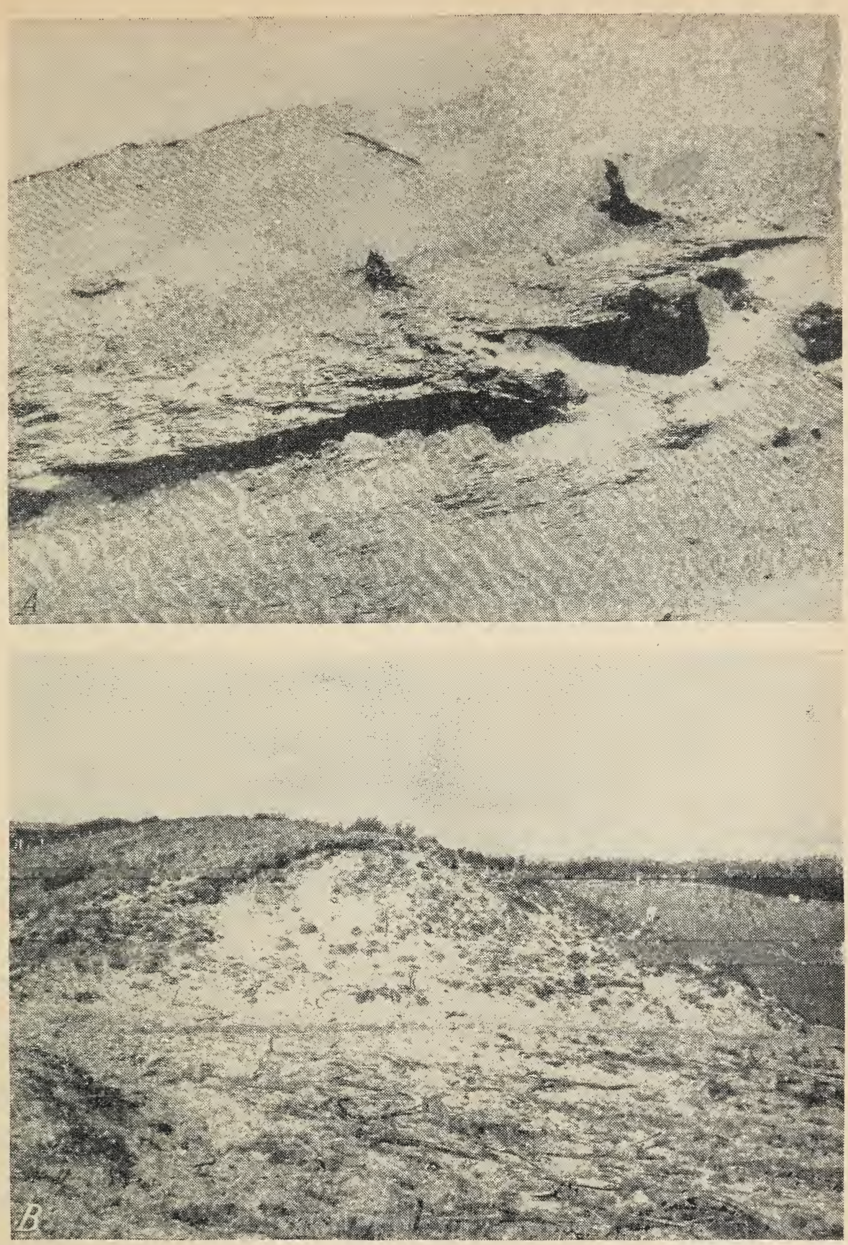

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Figure 6.—Fire and grazing are important causes of active dunes. *A*, Charred stumps stand as a last vestige of a mature coastal forest first destroyed by fire, then engulfed by great masses of dune sand; *B*, trailing by cattle destroyed the sod and the black sand layer and started a blow-out that will increase in size unless protected.

section of the Oregon coast. Much of this destruction has taken place within the memory of the present residents.

There is a tendency in the coastal regions of the Northwest, with a high annual rainfall averaging 60 to 70 inches, to consider that a heavy cover of moss or bentgrass sod replaces the more palatable forage and that overgrazing, therefore, may affect the kind of cover but does not contribute to erosion. This is the case on that portion of the area where a definite black sand surface layer has high humus content; but where this black sand has been covered or destroyed, the gray sand supports a relatively thin cover, and overgrazing is extremely hazardous. Any grazing on the dunes where gray sand is at the surface is almost certain to cause further thinning of the cover and will result in eventual destruction of the vegetation and the reduction of the area to an eroded wasteland.

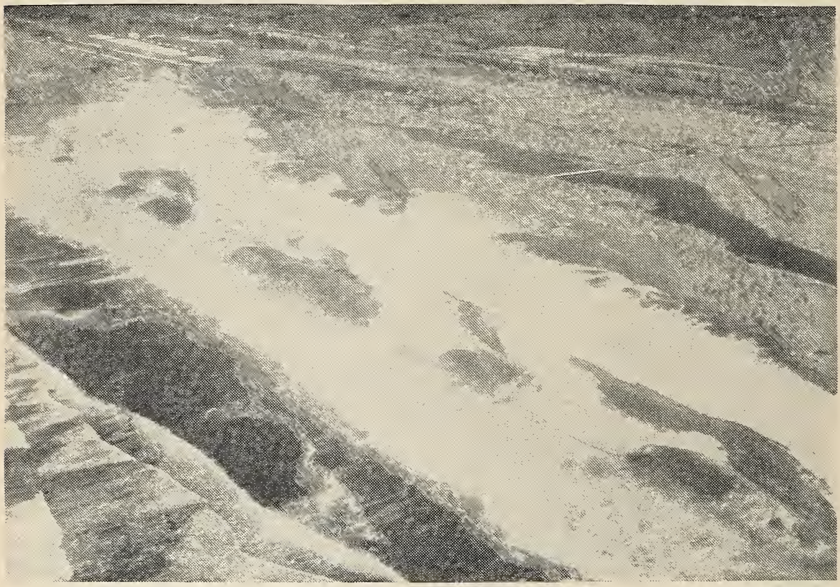
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Figure 7.—This area of active sand on the Clatsop Plains once was stabilized by a permanent grass cover. After the cover was destroyed by the grazing and trailing of livestock, more than 40 million cubic yards of sand was carried inland over valuable property by landward winds. The protective foredune was almost destroyed.

Perhaps the greatest damage, however, has been done by cattle, horses, and sheep trailing back and forth across the dune ridges. Before long this repeated trailing cuts through the sod, down into the black sand layer, and finally through into the gray sand (fig. 6, *B*). Then the gray sand blows out and is carried by the wind and deposited farther inland until the gap has widened and begins to undermine the sod, which crumbles and leaves an ever-widening area to scour. This sort of disturbance caused approximately 40 million cubic yards of sand to blow inland from the old foredune that extended from the mouth of the Columbia River to Tillamook Head, and resulted in the almost complete destruction of that foredune (fig. 7), and in an undetermined amount of damage to the land on which this sand was deposited.

JETTIES AS A CAUSE OF ACTIVE DUNES

Sand coming down the Columbia River built a bar across its mouth. Prior to 1885 a 20-foot ship channel was maintained by dredging. A south jetty was begun in 1885. Later, this jetty was built to a maximum length of 7 miles, and a north jetty was extended 3 miles to sea. Construction of the jetties resulted in scouring of the channel to a depth of 47 feet in 1937. Distribution of much of the sand scoured from the channel has been north and south from the mouth of the river, and a low-lying sand flat south of the river has built oceanward. It has attained a maximum width of more than one-half mile near the jetty and extends several miles southward, gradually narrowing until it meets the old beach line.

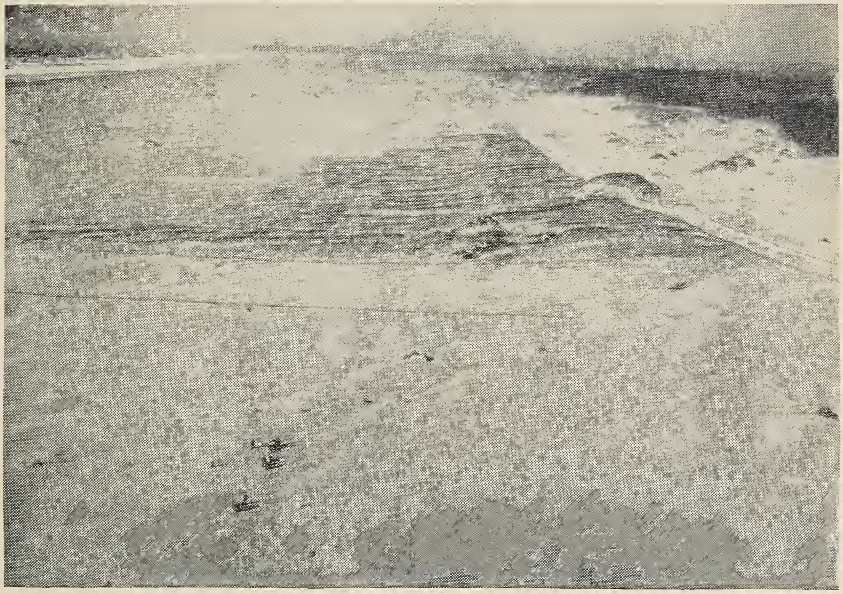

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FIGURE 8.—The wide sand flat built oceanward too rapidly to permit normal vegetative succession to hold the sand in check. Scattered hummocks toward the beach were built up by plants of European beachgrass; but because of the rapid accumulation of sand near the jetty at the mouth of the Columbia River, the beach did not remain stationary long enough for a continuous littoral dune to build up. Nursery-trial plots in the foreground.

Ordinarily as a beach builds oceanward the process is so gradual that vegetation keeps pace, and the sand is stabilized as rapidly as it is deposited. Most of the sand from the beach, blown inland, is caught by the coarse vegetation of the littoral dune and aids in building this dune higher. In the case of the wide plain south of the Columbia River jetty, however, the beach line built oceanward too rapidly for the vegetation to keep pace (fig. 8). Occasional clumps of sand-stilling grasses washed onto the flat, took root, caught sand, and built up scattered hummocks, but generally there was little vegetal cover to hold the sand. The prevailing winds were free to move the sand inland. Essentially the same problem has resulted in all cases where jetties have been built at the mouths of rivers on the north Pacific coast.

Minor Causes of Active Dunes

There are numerous minor causes of active dunes. Among them are the construction of roads, wearing of trails, regrading for building sites, and cultivation. In general, any destruction of the vegetal cover in an area of sandy soil is likely to start sand movement. The unprotected site starts as a blow-out, which increases in size until its control becomes a task involving a great expenditure of funds and labor.

Cultivation of sandy soils in the coastal section of the Pacific Northwest normally is limited to those areas where the black sand layer, relatively high in humus, is present at the surface. This layer may vary in depth from 1 or 2 inches to 2 feet. In the Clatsop Plains section, it is normally 6 to 12 inches in depth. In locations not protected by trees, where the soil is exposed to high winds, extreme caution must be employed in cultivation; otherwise the soil is likely to blow, and the eventual loss of the valuable surface layer results.

METHODS OF CONTROL

General Procedure

The first step in dune control should be a complete recognition of the principle that a mantle of protective vegetation develops rapidly enough to keep pace with normal dune-building processes; also that destruction of this vegetation on small or large areas initiates a cycle of events that eventually may lead to widespread land and property damage. Most of the causes of active dune areas are man-induced, hence prevention is possible through individual and community effort. Relatively simple measures are effective in controlling small areas of exposed sand when applied immediately after the damage is noted. Simple procedures quickly control the movement of sand exposed by construction operations, stock trailing, and spot fires. Much more complex and expensive procedures are required to effect control after the area becomes large.

The eventual goal in controlling the movement of active dunes is the reestablishment of a dense permanent cover of vegetation. This cover may be herbaceous, consisting of grasses and legumes, or woody, employing shrubs and trees. These types of cover are not easily obtained or quickly achieved on eroding sands subject to high wind velocities. Provision must be made for stilling the sand, and for an orderly process of building up the fertility and organic matter of the surface until the final and permanent types of vegetation can be seeded or planted.

Sand movement may be arrested by mechanical means or with types of vegetation suited for this purpose. Fences of proper type will check the movement of sand temporarily until vegetation can be established. On the Clatsop Plains area, double lines of picket fences have been used to assist in the construction of a foredune. On wide sand flats where the parallel dune topography has been destroyed or has failed to develop, fences may be used to speed the reconstruction of this topography. Sand fences on such areas serve to build a dune ridge during the summer, which may be planted the following winter. Brush matting or surface litter may serve temporarily to arrest the movement of surface sand.

There are several grasses that serve effectively in the stilling of sand movement, and as a first step toward a permanent vegetation. They thrive in shifting sand and survive inundation, but never form a permanent cover. These grasses are transplanted to form an open stand that protects the surface against the scouring action of the wind and cause sand deposition. This method of sand stilling is generally preferable to the use of mechanical means except in special cases, because it is more economical and at the same time more completely effective.

Following the establishment of sand-stilling grasses, an intermediate step usually is required before the final and permanent vegetation is established. An essential feature of this step is the introduction of a herbaceous or woody legume along with other secondary plants. The legume is essential because eroding sand areas are very deficient in nitrogen and organic matter. These deficiencies make it difficult to establish permanent types of vegetation. Commercial fertilizers may be used to supply nitrogen; however, leguminous plants have been found efficient in supplying both this element and desirable amounts of organic matter. The legumes and other plants used in secondary seedings must withstand some sand movement until litter is produced.

The type of permanent vegetation to be used is determined by the local situation and involves problems of land use. A mixture of permanent grasses and legumes provides adequate ground cover and protection. Woody plantings may be used where it is desired to prevent trespass grazing, where tall vegetation is required to protect lands to the leeward, and especially to assist in smoothing out irregularities in topography. Irregular topography containing pockets and hummocks intensifies wind eddies and promotes scouring.

Before installing mechanical controls or making plantings it is necessary to plan the operations carefully, so that they may follow an effective sequence and be accomplished at minimum cost. Attention must be given to natural forces, such as seasonal direction and velocity of wind, relative amounts of sand being transported, normal topographical features, climatic conditions that influence planting, and the proper land use of the area. Provision must be made for adequate supplies of good planting stock and seed. Assurance must be obtained that plantings will be maintained and adequately protected.

Sand Fences

Sand fences have two primary uses: (1) When located approximately at right angles to the prevailing winds, they cause temporary deposition of sand, and (2) when set at a tangent to the prevailing winds, they direct the sand-laden wind and may, in some instances, result in a desired intensification of scouring.

Picket-type sand fences placed parallel to the beach were employed effectively to build the littoral dune (foredune) on the Clatsop Plains dune area. It was necessary to use two parallel lines of fence 30 feet apart to obtain the proper and stable conformation of this dune. The

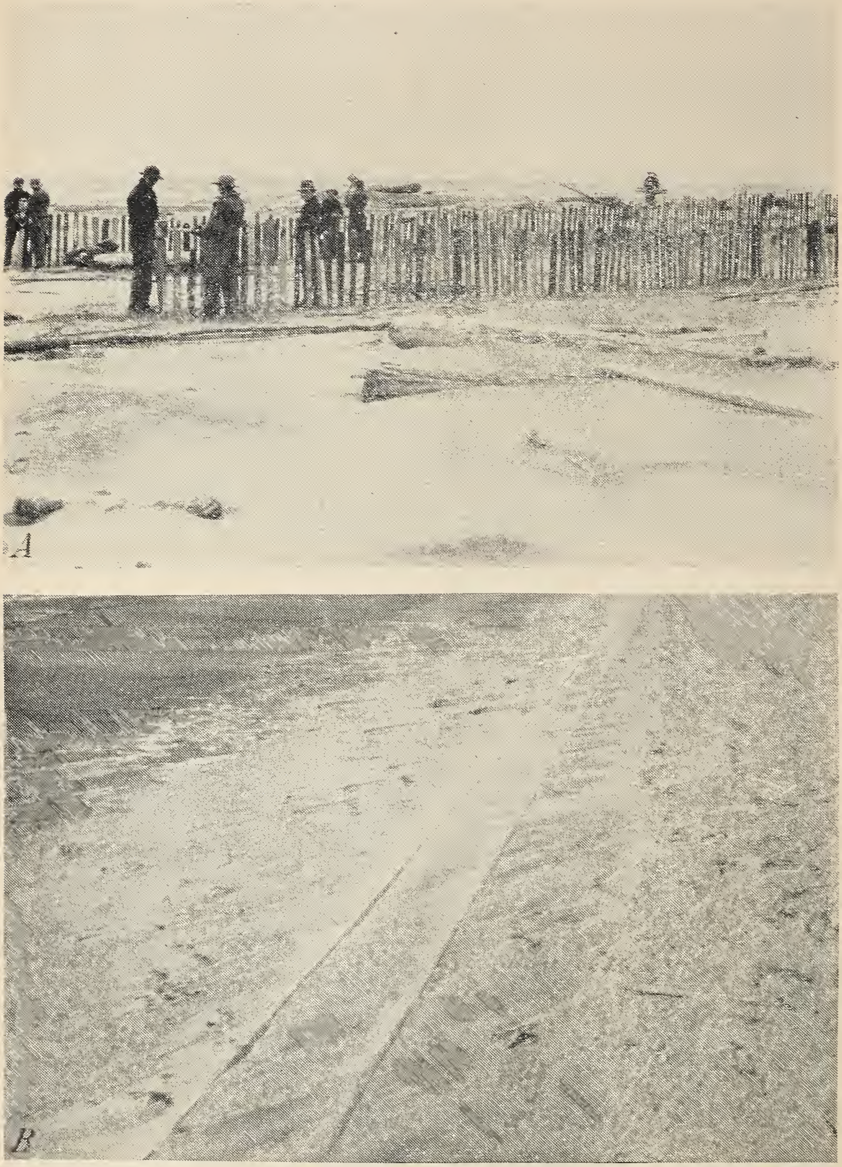

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Figure. 9.—Picket-type sand fences were used to build an artificial foredune on the Clatsop Plains dune area. *A*, Method of constructing the sand fence. It will be noted that the picket fences are even and well-maintained. *B*, Sand fences have arrested sand movement in the form of a broad-base dune that will be planted to beachgrasses.

fences were made of pickets 4 feet long, 4 inches wide, and ¾ inch thick. These pickets were made from salvaged lumber or hand split from western red cedar. One end was pointed, and the stakes were driven into the sand approximately one-fourth of their length (fig. 9, *A*). It was found essential to keep the top of the fence even so that the dune formed would have an even crest. All unevenness of topography causes wind agitation around the high spots and increases the unevenness, which is detrimental to the success of the structure.

The correct distance between fences is known to depend on the size of sand particles and mean wind velocity. The distance between pickets in the fence usually can be considered correct if the space between pickets is approximately equal to the width of the pickets; less than this width tends to direct the wind current along the fence, thus causing scouring. If the width is greater, scouring occurs between pickets. When the fences are spaced too far apart, two separate dune crests are formed, which is not desirable. When the fences are too close together or a single fence is used, a sharp crest is formed on which it is impossible to establish vegetation. Proper spacing of the fences results in the formation of a broad-base dune with a single, gently rounded crest (fig. 9, *B*).

Movable sand fences have been constructed in sections on some control projects. These were made similar to the old "A" style snow fence. These are much more costly to construct and maintain than the picket type. Brush barriers sometimes are built more cheaply than the picket-type fence where materials are available. These may be constructed by weaving brush into wire and fastening them to posts at 10- to 12-foot intervals or by digging a trench and burying the ends of the brush to form a dense barricade with the upper tips leaning away from the prevailing wind (fig. 10).

Fences and brush barricades are, however, only temporary sand-stilling measures and may be used to check the progress of sand only until it can be covered with the vegetation essential for permanent control.

Brush Matting

Brush matting sometimes is used to stop sand blowing. It serves as a temporary check to further scouring and acts as a mulch. The brush is laid flat on the surface of the ground, with the second row partly overlapping the first, shinglewise. On steep banks the brush may be staked down and further secured by wire.

The value of brush matting is only temporary in nature, as brush soon loses its leaves and becomes ineffective. In most cases permanent plantings could be made with very little additional expense. Matting is successful only if combined with a seeding of sand-stilling grasses or shrubs. In practice, however, it has been found very difficult to obtain a uniform stand of vegetation in this manner. Spots not fully protected by the permanent vegetation are subject to the scouring action of the wind as the mat deteriorates.

Oil for Holding Sand

Oil has no place as a means of holding sand in the north Pacific coastal dunes, except possibly for use on trails and in similar sites

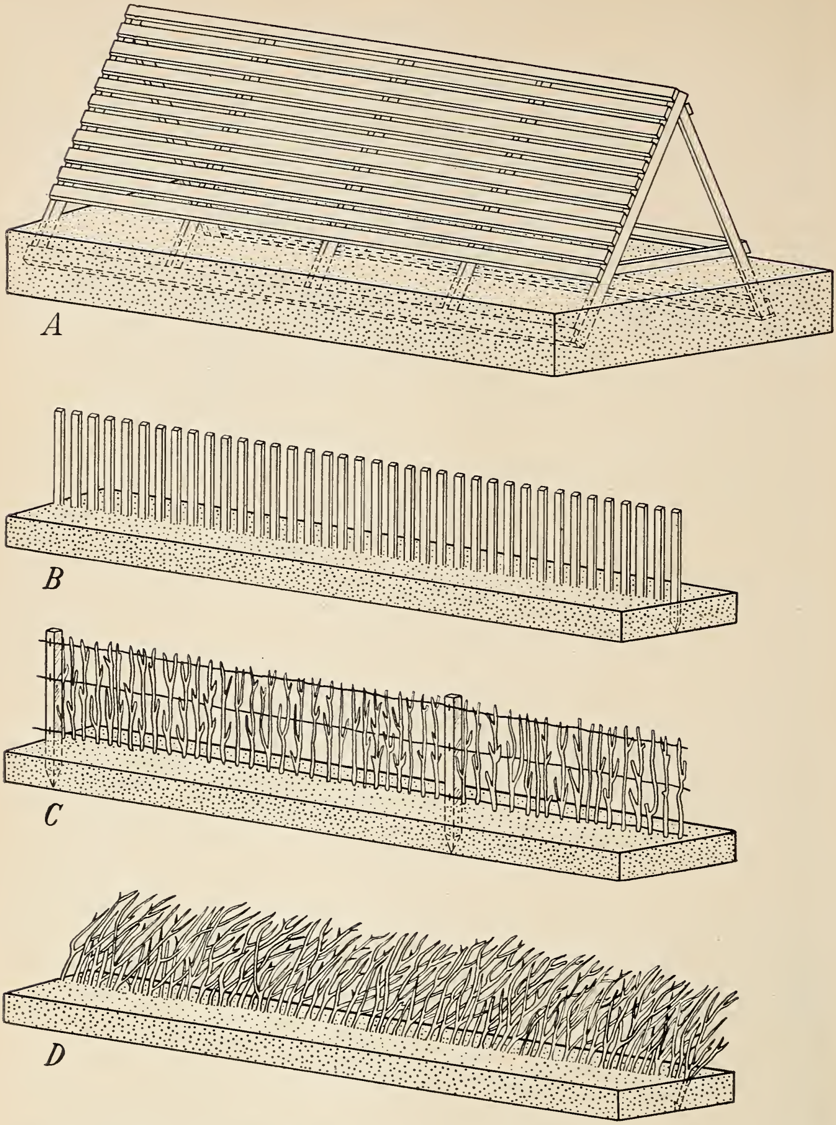

Figure 10.—Types of sand fences used throughout the world to still sand and form foredunes or to act as barriers for the protection of areas to the leeward. *A*, The "A"-style snow fence constructed in movable sections. *B*, Picket-type fence. Each picket is movable—this makes for ease in establishment and maintenance. *C*, Brush barrier constructed by weaving brush into set wires. This fence is immovable and must be reconstructed each time it is desired to raise the dune. *D*, Brush barrier, probably the cheapest fence to construct where brush is available. It must be rebuilt each time the dune is raised.

subject to heavy use. In the more arid regions along the Columbia River east of the Cascade Mountains, hot crude oil sprayed on the sand has been fairly effective in preventing it from drifting onto the highway and railroad right-of-way. Oil, however, is not a permanent control, is costly, and makes against the establishment of a permanent plant cover.

Rock, Gravel, Clay, and Refuse for Holding Sand

Rock or gravel serves to protect the surface of the sand from the wind and so prevents scouring; however, where subject to heavy use or sand drifting, the rock or gravel becomes buried and is no longer effective. Clay is used to some extent in the coastal section to bind the sand and prevent erosion by wind. It is costly and likely to be only temporary in effect.

Refuse, such as street sweepings, has been used with success to reclaim limited areas of sand dunes. Such material is not available in quantities except in large cities, few of which are found near sand-dune areas.

Sea walls of stone or concrete are effective ordinarily in preventing sand from moving inland; but, if the source of sand is extensive, dunes of sufficient size to inundate any sea wall may develop.

VEGETAL CONTROLS

Wherever permanent control of active sand or dunes is desired, vegetation must be established. This is true even when mechanical devices are employed to arrest sand movement temporarily. In most cases, three steps are required before the final and permanent vegetation is obtained: (1) The initial step, employing sand-stilling grasses, (2) the intermediate step, using a herbaceous or woody legume with other plants after the sand-stilling grasses are established and the amount of sand deposition has been decreased, and (3) the final step, seeding or planting permanent vegetation in the growth of intermediate plants. There are conditions under which the intermediate and final steps can be combined or under which the final step develops naturally in the intermediate planting when good protection is afforded.

Initial Step—Planting Sand-Stilling Grasses

Where to plant.—Relatively close plantings of sand-stilling grasses do two things: (1) They protect the surface, thus preventing sand scouring, and (2) they decrease the velocity of the wind, forcing it to deposit part of the sand it carries.

On any unprotected site where sand is being blown, two well-defined zones must be recognized when making control plantings, the zone from which the sand is being blown, and the zone of deposition. The zone of deposition lies to the leeward of the source, relative to the prevailing winds. The relative position of the source and area of sand deposition may vary with a seasonal shift in prevailing wind direction. This is definitely the case along the Oregon-Washington coast line, where in the summer the prevailing winds are north to northwesterly and the direction of sand movement is toward the southeast. In the winter, the storm winds causing the greater part of the sand movement are southerly, and the prevailing direction of sand movement is north to northeasterly. East winds occasionally move some sand back toward the source. This westerly movement is temporary, however, and, over a longer period, the sand continues to move inland. Therefore, the general movement of sand is in an easterly direction on any unprotected site or from the beach inland.

Only by checking the sand movement at its source can an area be controlled effectively. Because any exposed area of sand may constitute a source, it is essential to apply control practices to the entire area of exposed sand. Unless complete vegetal cover can be given a dune area, control measures are not worth starting. Not even a few square yards should be left unprotected. In order to prevent plantings or other control devices from becoming buried too deeply by sand, it is advisable to begin the control at the windward margin and progress toward the area of deposition (fig. 11). On beach property this means starting a short distance behind the extreme high-tide line with a foredune, and then progressing inland with plantings.

Planting of a foredune requires special attention to insure success. This dune is first built up, as discussed under "Sand Fences," to a height only sufficiently above the beach to keep storm tides from washing over the top. Plantings of beachgrasses must then be made, as building higher before establishing vegetation requires added cost of maintenance in later years, to overcome undercutting by wind or water, because no organic matter and plant roots were incorporated in the bottom section of the dune. A strip of planting approximately 50 feet wide should be made to windward or toward the ocean from the first fence line. The space between the two fences and a strip at least 100 feet to leeward from the back fence should likewise be planted. The plantings should be extended gradually as the dune builds up, until ultimately a base at least 500 feet wide exists as the dune reaches maturity.

In the case of a blow-out farther inland, the planting likewise should start to the windward and progress inland. On areas small enough to allow complete planting within a short time, the order of planting is not important.

When to plant.—On the dune areas of the north Pacific coast the season for transplanting sand-stilling grasses is essentially the winter rainy season, lasting roughly from November 1 to May 15, although the season may be extended considerably, depending upon the weather conditions. In sections of the United States subject to more severe winter weather, planting is confined to fall and early spring. Planting usually is successful during cool weather, even without precipitation. Low-lying sites, moist in early summer, may be planted more safely later in the spring than may the higher, drier sites.

Plantings for the construction of the foredune along beaches should be done in the early spring after the danger from severe storms is over. Earlier plantings on foredunes are faced with destruction from excessively high tides. Plantings made during early spring establish themselves before warm weather and grow rapidly, as new sand is accumulated on the dune throughout the season. A good planting will accumulate as much as 2 feet of sand annually.

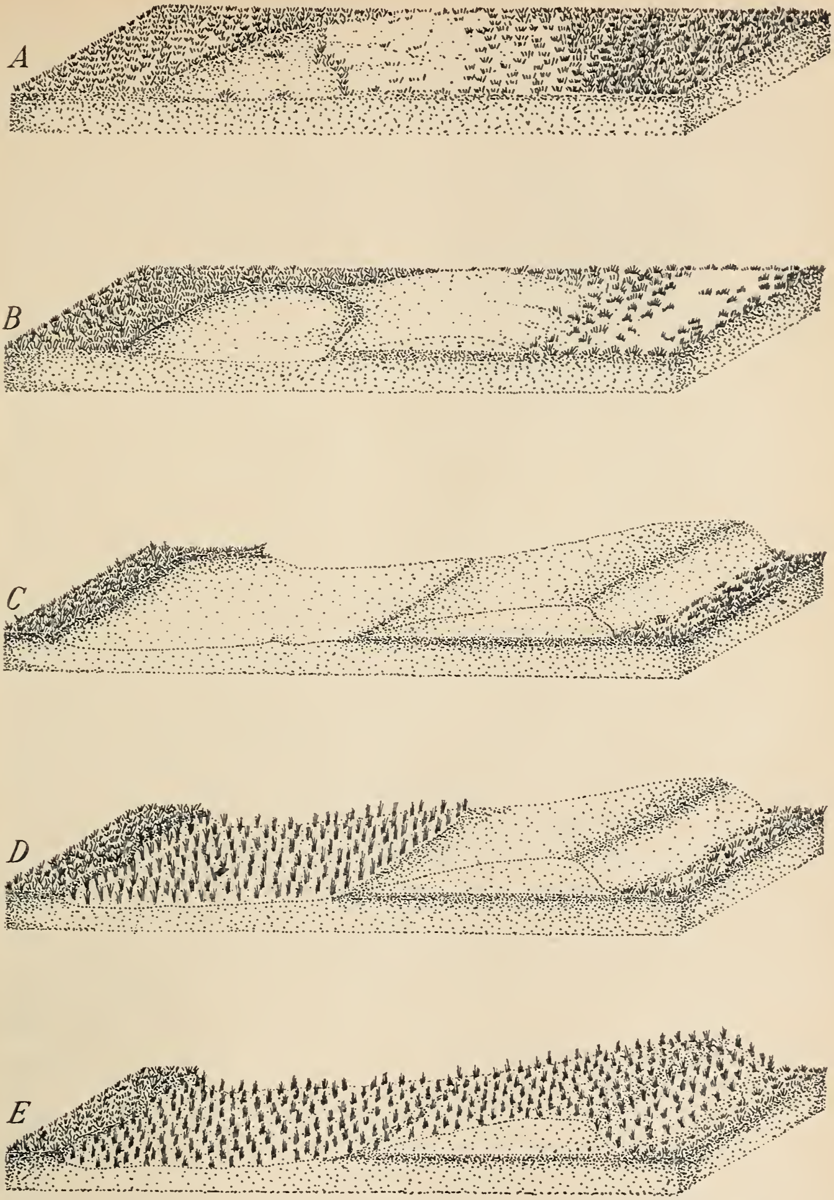

FIGURE 11.—Origin and control of a blow-out. *A*. A blow-out begins where the vegetation is disturbed by burning, grazing, excavation, or other cause. *B*. Blow-out increases in size as sand is scoured from bare area and deposited in vegetation on the lee side. *C*, A dune is formed and begins to move with the prevailing winds. *D*, Planting of beachgrass is begun on the windward side (the source of sand) and progresses toward the zone of deposition. *E*, The dune is stabilized completely by a uniform cover of vegetation and is ready for permanent seedings or plantings.

Areas subject to winter submergence should be planted in the spring as the water level recedes. Plantings that have not gone through one growing season fail to withstand extended submergence and may be drowned out. After one growing season, plantings of European beachgrass are able to withstand long periods of submergence with less damage.

What to plant.—Beachgrasses and dunegrasses are the most universally useful sand-stilling plants for initial plantings on coastal areas. When properly used, they are effective even against winds of high velocity, heavily laden with sand. They can be produced cheaply, and the plantings are relatively cheaper than other means of initial stabilization. Their success as sand-stillers is due to (1) the mechanical effect of the coarse stems that are allowed to project above the surface and give it protection against scouring, (2) their rapid growth through heavy deposits of sand which may amount to 2 feet or more in a single season, (3) the rapid multiplication of the stems from underground buds so that large clumps soon are formed, and (4) the development of an extensive root system and, in some cases, the production of horizontal underground stems capable of growing into unvegetated areas and producing new clumps.

Sand-stilling grasses are transplanted as clones, a clone being a single stalk taken from a clump and capable of producing a new clump. Sand-stilling grasses reproduce and form new plants principally by offshoots, or tillers. They seldom seed well, because of adverse growing conditions, and depend largely on the offshoot method of reproduction. In practice, it has been found that even when seed is available, it is difficult to sow it in shifting sand; for it will either be blown out or become covered to excessive depths. The method of establishing the initial transplantings of grass has proved to be far more satisfactory.

Grasses of a sand-stilling nature develop from one to many shoots above ground or tillers from each clone. These shoots usually are developed in clumps. Toward the lower end of the shoots small buds, hidden by the lower sheathing, or brownish leaves, are formed. These buds are capable of forming new plants and are an essential part of any vegetative material used to reproduce new plants.

Planting stock of beach or dune grasses may be obtained from existent vegetation or from reproduction nurseries. The latter method is most economical if large areas are to be planted, as grass stock can be harvested more readily and more and better stock becomes obtainable from an area.

The season for harvesting planting stock is essentially the planting season. Stock of sand-stilling grasses should be collected during the cool, wet months from late fall through early spring at a time when the plant is most nearly dormant. Collecting stock during this season provides planting materials that have the greatest amount of stored food. Thus, greater vigor is inseminated into the new planting than when succulent plants are harvested. American dunegrass, *Elymus mollis* Trin. does not survive well if other than dormant planting stock is used; whereas, the beachgrasses, *Ammophila* spp., will survive well as long as the stock is harvested and planted in cool weather.

The stock is harvested most easily by cutting 2 or 3 inches under the surface with a flat-bladed garden spade. Cutting at this depth usually leaves one or two underground nodes on the stems, which are enough to give satisfactory planting stock (fig. 12, *A*). The type of spade used should be 7 to 8 inches wide and straight across the cutting edge, so that all materials are cut to an equal depth. Stock can be pulled almost as easily as it can be dug when there has been no sand deposition during the current growing season. If there has been sand accumulation, pulling is not practicable.

The grass, after being dug, is shaken free of sand, the dead trash cleaned from the culms, and the hill or clump broken up into small bunches. The underground stems are broken back to one or two nodes; more than two are of no value and delay planting. For convenience in accounting for stock and in handling, the culms are tied into bundles of 10 pounds (fig. 12, *B*). After the bundles are tied, the tops of the stock are cut back with an ax until the over-all length is about 20 inches. The long leaves, in this way, also are cut off, as they serve no useful purpose and offer added surface for evaporation. If the leaf surface is excessive, the winds cause sufficient agitation to loosen the stem in the sand, thus retarding good growth.

In nurseries, stock can be dug each year if given an annual application of fertilizer. A new crop will come from underground stems or rootstalks. Stock can be completely dug on areas where there is no drifting sand, or can be thinned to the approximate original planting on areas of drifting sand.

Planting stock of sand-stilling grasses can be stored during the cool winter months for several weeks without destroying the vigor of the plants. Storage, during early fall or after growth begins in the spring, must be held to a minimum; and it is advisable to store less than a week in these seasons, as the stock may either heat or, during dry weather, dry out and become of little value.

Storing of grass stock is confined to heeling-in on the nursery or planting site. No cold or common storage under controlled conditions is necessary or practical, as the value of stock compared to bulk does not make special storage feasible. It is important when heeling-in to keep the beds narrow, not over two bundles wide, in order to avoid heating of the grass. The method of heeling-in is illustrated in figure 13. Bundles should be buried in the trench to a depth of approximately one-half their length, and sand firmed around them. The grass should not be heeled in where water will stand on the bed, as this decomposes the basal buds of the stem, thus lowering potential survival and plant increase.

Stock has been shipped considerable distances during cool weather without apparent harm. The Soil Conservation Service has transported these grasses 250 miles by truck. Stock has been shipped successfully by rail and boat in crates without special packing. Shipping should be done during cool weather.

How to plant.—Transplanting of sand-stilling grasses usually is done by manual labor. Various tools have been used to make the openings in the sand for the stock. Among the better types are the prod, made from a peavy handle, spud bars of various shapes and sizes, and several types of shovels (fig. 14). The character of the sand will determine to some extent what tool can be used best. Most of the

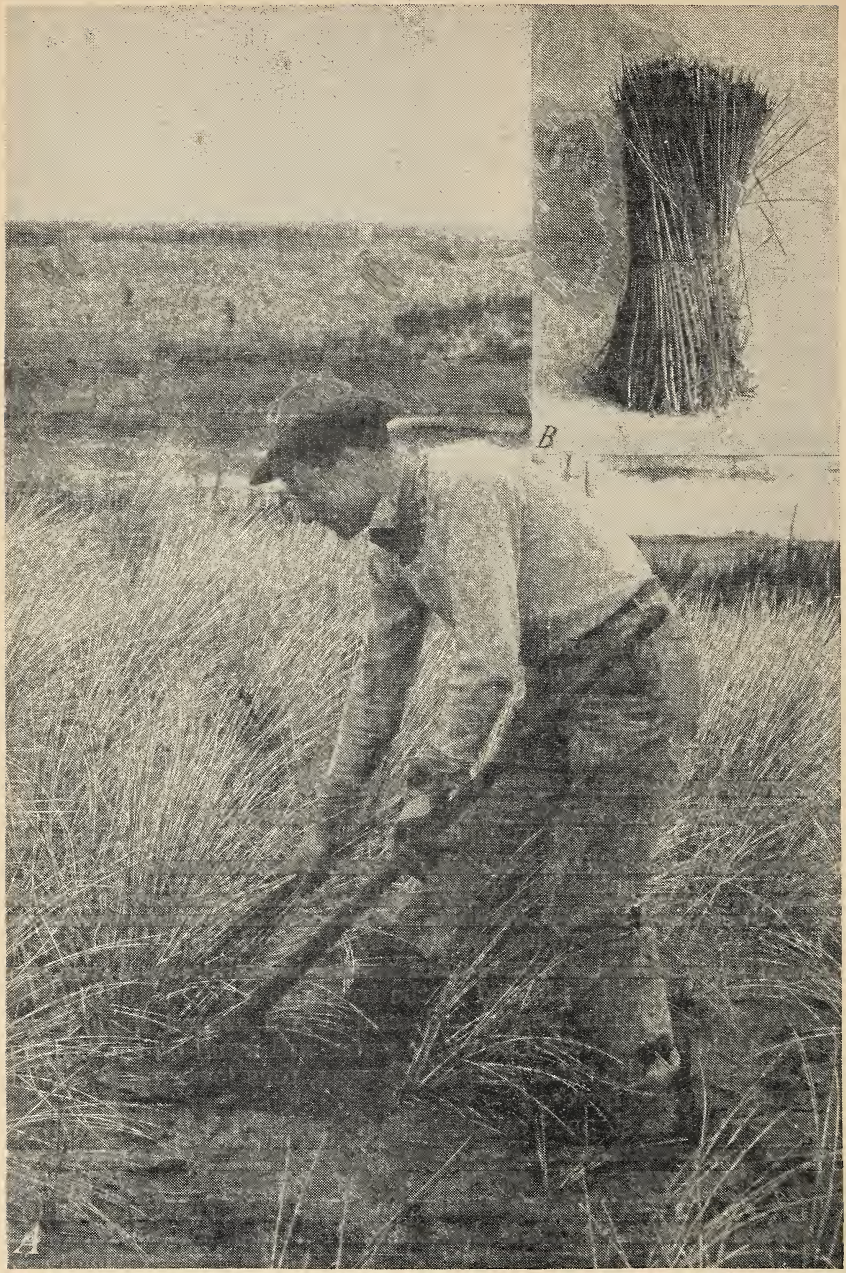

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FIGURE 12.—Digging and preparing European beachgrass for planting stock. *A*, Planting stock is taken from a vigorous stand that is relatively free from dead growth and trash. *B*, Planting stock is carefully cleaned, trimmed, and tied in 10-pound bundles containing 800 to 1,000 culms.

sands on the coasts of Oregon and Washington are firm enough when wet to allow the use of a spade, such as the common tile or ditching spade. The blades of these spades average 14 to 16 inches in length and 5 to 6 inches in width. In the coarser and looser types of sand a dibble or prod may prove more feasible, because of the firming effect it has on the side of the hole. This prevents a large amount of sand from shifting into the bottom of the hole or having the side walls slough in.

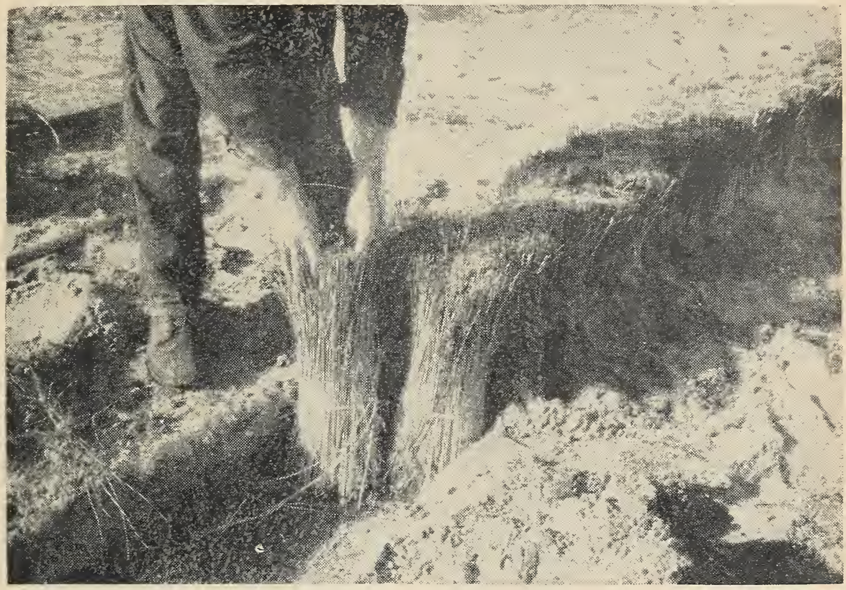

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Figure 13.—Method of heeling-in bundles of planting clones.

In selecting a planting tool the important things to consider are whether: (1) The tool is capable of making a slit or hole at least 12 inches in depth in one thrust, (2) the tool is as light as possible but rigid and able to withstand hard usage, as an extra pound or two of weight cuts down considerably on a man's daily planting output, and (3) the tool will open the slit or hole with the least resistance, as time and energy used are important in determining the cost of planting.

When sand-stilling grasses are being transplanted, two men usually compose a planting team (fig. 15). One man makes the openings in the sand. The other follows to insert the required planting stock to a depth of approximately 12 to 14 inches and to firm the sand around the stock with heavy heel thrusts in order to eliminate air pockets around the roots.

The planting crew can be composed of any number of teams desired, but usually a dozen teams of unskilled laborers are all that one foreman can supervise properly, as it is equally important to firm the plants of sand-stilling grasses as plants of woody species, though straight rows, except in nurseries, are not important.

Rate of Planting.—Initial plantings of sand-stilling grasses usually are made on nonvegetated areas, in order to still the sand and prepare

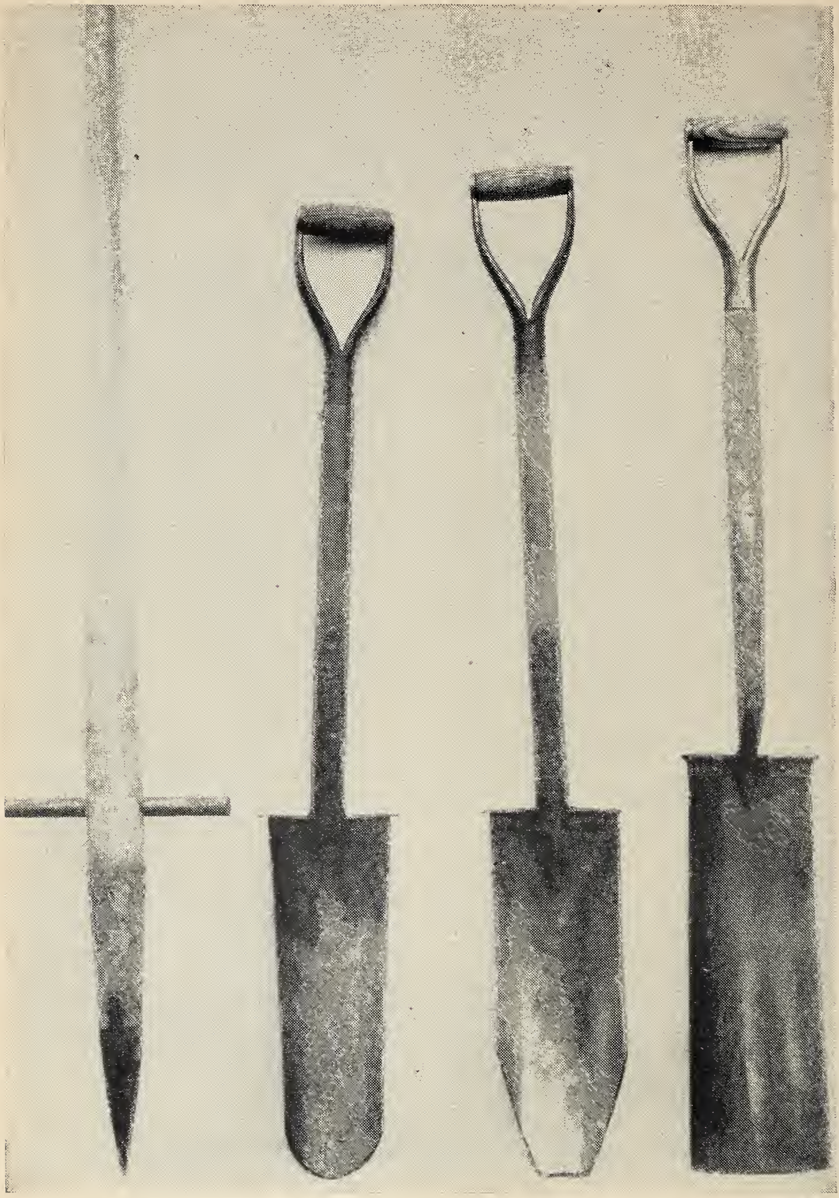

FIGURE 14.—Tools used for planting beachgrasses (left to right): Peavy without hook; tile or drain spade; modified post-hole or ditching spade; and post-hole or ditching spade. The tile or drain spade and modified post-hole or ditching spade are the most effective hand planting tools.

the site for secondary seedings and plantings. Site conditions will vary greatly on large areas; consequently in order to control sand movement effectively on all these sites with the greatest economy, several different hill spacings and numbers of culms per hill are necessary, under varying conditions.

The culms are planted so that they extend above the surface of the sand 6 to 8 inches (fig. 16). These stems serve as a physical barrier to the wind; and, when the spacing and rate of planting are correct, sand is deposited. Usually on intermediate sites on the Pacific coast a hill spacing of 18 inches, with three stalks (culms) per hill will suffice. On severe sites or on areas surrounding particularly valuable property, closer planting with the hill spacing approximating 12 inches and 3 to 5 culms per hill, is needed. Sites extremely well protected may be stabilized by wider than normal spacings. A summary of planting rates that have been found successful on the Clatsop Plains area is given in table 1. This table also shows the relationship of site conditions and other factors that determine successful rates of planting.

Table 1.—*Hill spacing, number of culms per hill, and fertilizer application, recommended to arrest sand movement effectively and maintain plant survival on typical eroding sites of marine sand formations on the north Pacific coast when planted with European beachgrass*

Site conditions	For immediate stabilization		For deferred stabilization	
	Spacing	Culms	Spacing	Culms
	Inches	*Number*	*Inches*	*Number*
Steep slopes:				
Windward:				
Dry	12 x 12	[1] 3	18 x 18	[1] 5
Moist	18 x 18	5	18 x 18	3
Leeward:				
Dry	18 x 18	[1] 5	18 x 18	3
Moist	18 x 18	[1] 3	24 x 24	[1] 5
Flat areas:				
Exposed to high winds:				
Dry	18 x 18	[1] 5	18 x 18	[1] 3
Moist	18 x 18	5	18 x 18	3
			24 x 24	[1] 5
Exposed to moderate winds:				
Dry	18 x 18	[1] 3	18 x 18	5
Moist	18 x 18	5	24 x 24	[1] 5
Irregular topography:				
Exposed to high winds:				
Dry	12 x 12	5	18 x 18	[1] 5
Moist	18 x 18	[1] 5	18 x 18	[1] 3
Exposed to moderate winds:				
Dry	18 x 18	[1] 5	18 x 18	[1] 3
Moist	18 x 18	5	18 x 18	3
Valuable property:				
Exposed to high winds:				
Dry	12 x 12	[1] 5	12 x 12	3
Moist	12 x 12	[1] 3	18 x 18	[1] 5
Exposed to moderate winds:				
Dry	12 x 12	[1] 3	18 x 18	[1] 5
Moist	12 x 12	3	18 x 18	5
Foredune:				
Windward face	18 x 18	[1] 3	----------	----------
Leeward face	18 x 18	[1] 5	----------	----------
Top	12 x 12	[1] 5	----------	----------

[1] Fertilized.

Several planting patterns have been tried on the dune areas of the world, varying from checkerboards with alternate squares unplanted to strips with intervening unplanted gaps. Under conditions prevailing on the coast of the Pacific Northwest, partial plantings have

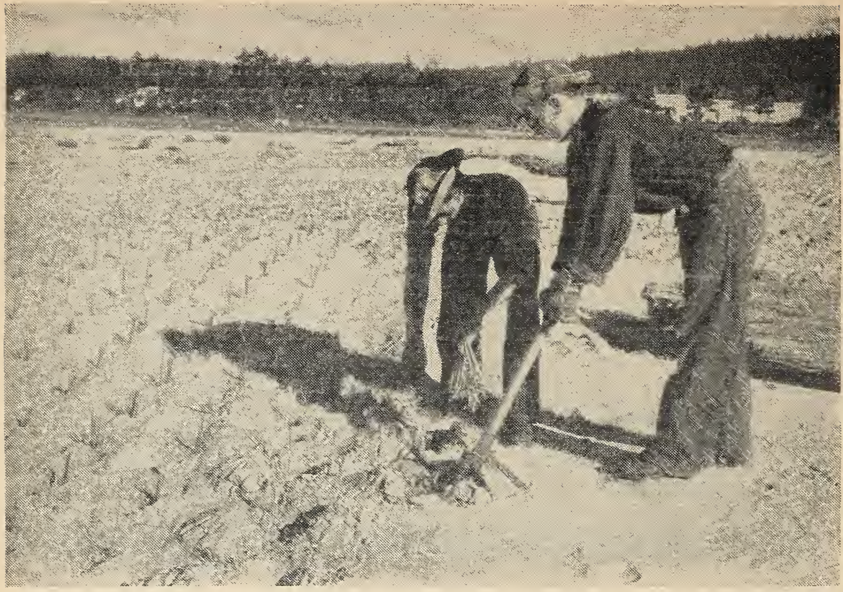

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FIGURE 15.—Two men compose a planting team. One makes the holes with a spade or other instrument; the other inserts planting stock and firms the sand with his heel.

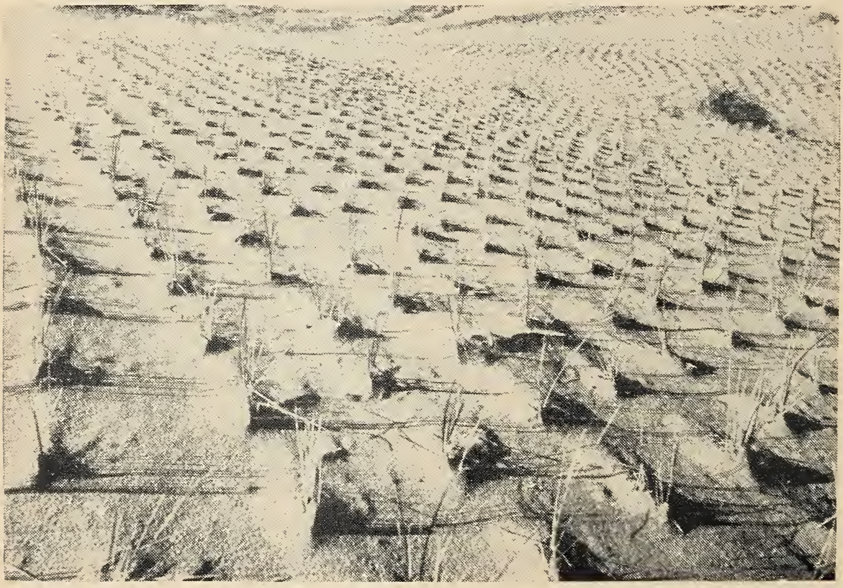

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FIGURE 16.—A field the first year after planting to European beachgrass. The planting stock, projecting about 8 inches above the sand level, decreases the wind velocity and causes sand deposition if the spacing is correct and the planting is maintained.

seldom, if ever, been successful. Maintenance costs are disproportionately higher than where solid plantings are used. Partial planting patterns usually cause excessive scouring or sand deposition on the area; this unevenness or hummocking requires additional maintenance, as unmaintained plantings deteriorate and result in loss of all control efforts.

True economy in plantings is accomplished only when hill spacing and number of culms per hill are adjusted to the site conditions.

Maintenance of initial plantings of sand-stilling grasses.—In the initial stage of dune control, accomplished by planting sand-stilling grasses, it is imperative to develop and maintain an even vegetal cover devoid of breaks until secondary or permanent cover is established. To accomplish this, some maintenance of these plantings is necessary on account of poor hill survival, excessively wide spacing, or failure to plant all exposed areas. This maintenance planting can be done best by going over the initial plantings every winter and repairing any breaks or thin places, which might have developed during the preceding season. American beachgrass is the most satisfactory species for maintenance because of its extensive underground root system.

Kinds of sand-stilling plants.—Initial stabilization of moving sand on the Pacific Northwest coast has been accomplished largely through the use of three sand-stilling grasses: (1) European beachgrass, *Ammophila arenaria* (L.) Link, (2) American beachgrass, *Ammophila breviligulata* Fern., and (3) American dunegrass, *Elymus mollis* Trin.

In the initial plantings European beachgrass (fig. 17, *A*) has been the principal grass used, largely because of its known value for this purpose and to its availability. American beachgrass (fig. 17, *B*), a native of the Atlantic coast and Great Lakes region of the United States, has been tried on the Clatsop Plains dune area and found to be equal or superior to the European beachgrass, especially for maintenance-type of planting. Its superior habits are its great ability to spread rapidly by underground rootstocks, its dense and erect habit of growth, and its ability to withstand competition from other plants, particularly weeds common to coastal sand areas.

Planting stock of American beachgrass is available on the Pacific Northwest coast only at Warrenton, Oreg. American dunegrass (fig. 17, *C*) has been used to some extent for foredune planting. The foredune is the site on which it grows naturally. This plant has been used relatively little, because planting stock is not plentiful and increase is somewhat slow in the nursery and field, thus making control costs nearly prohibitive. This species does not thrive and give protection under the wide range of site conditions to which the two beachgrasses are adapted. It requires considerable annual sand deposition and grows best in close proximity to the beach.

Fertilizer application.—The application of fertilizer to plantings of sand-stilling grasses has given excellent results and is recommended. Weak plantings caused by too wide hill spacing, too few culms per hill, or adverse climatic conditions may be strengthened to become successful plantings by the application of a nitrogen-bearing fertilizer. Plantings made at reproduction nurseries should be given fertilizer applications annually. Fertilizer increases rapidity of growth so that

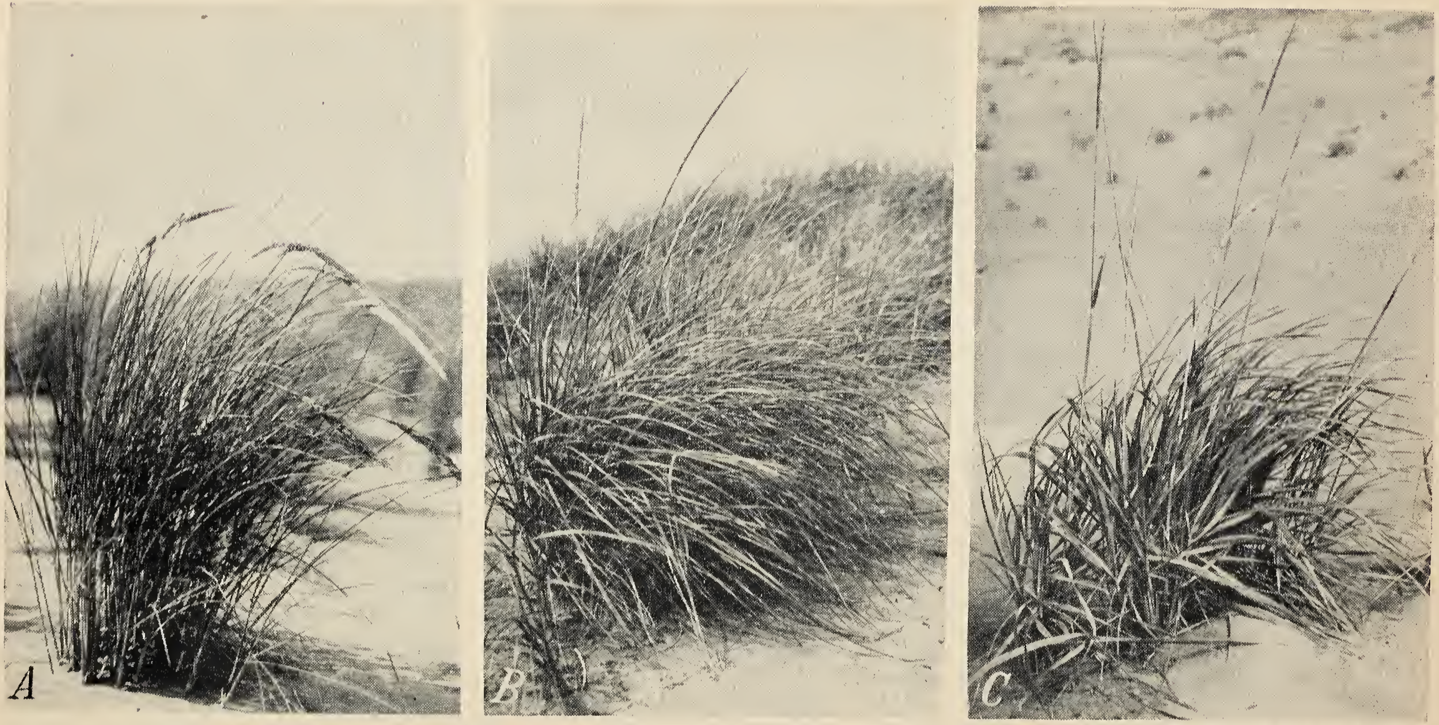

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Figure 17.—Typical 2-year-old plants of the sand-stilling grasses used for initial plantings. *A*, European beachgrass, *Ammophila arenaria* (L.) Link.; *B*, American beachgrass, *Ammophila breviligulata* Fern.; *C*, American dunegrass, *Elymus mollis* Trin.

spacings may be widened or the number of culms per hill lessened. In cases where stock is scarce, the use of fertilizer is much cheaper than deferring planting until more stock becomes available.

The rate of fertilizer application may vary, but it is not economical to apply less than 20 pounds of nitrogen per acre (this amounts to 100 pounds of 20 percent nitrogen fertilizer). Field and nursery tests show that the most economical rate is 40 pounds of nitrogen per acre, if results are desired immediately or if stock is to be dug from the area. Table 1 shows the relationship between fertilizer application and the rate of planting.

Trials show, also, that inorganic nitrogen fertilizers give greater immediate results than the animal or vegetable-byproduct fertilizers, and that the cost per pound of nitrogen has been lower. Growth results 2 years after fertilizer application will be approximately the same with either inorganic or organic fertilizers, though first-year results definitely favor the inorganic materials. The choice of a fertilizer depends on cost, availability, ease of application, and time when the results are desired. The cost of fertilizer and application are minor in relation to the complete cost of stabilization.

Fertilizer applications are best made on the north Pacific coast dunes about April 1 to 15, or at the time when the most rapid spring growth is taking place. There is also plenty of moisture at this time to permit fertilizer penetration to the grass roots. Applications up to 40 pounds of nitrogen per acre may be made at one time without causing leaching in the sand. When more than this amount is applied, some leaching may occur.

Cost of planting.—Transplanting sand-stilling grasses is a costly undertaking. Costs will vary greatly, depending on site location, source of planting stock, type of labor used, extent of area to be controlled, and whether fertilizer is used.

Solid plantings made on the coast of Oregon have varied from $40 per acre, including stock, for a hill spacing of 18 by 18 inches with three culms per hill, to slightly over $100 per acre for a hill spacing of 12 by 12 inches with five culms per hill. Approximate costs per acre for the kinds of planting most commonly used are shown in table 2.

TABLE 2.—*Cost of planting*

Spacing	Culms	Cost per acre
Inches	*Number*	*Dollars*
24 x 24	5	21
18 x 18	3	41
18 x 18	5	47
12 x 12	3	95
12 x 12	5	108

When fertilizer is applied, the cost per acre will be increased according to the kind, amount, price of the fertilizer used and the cost of application. On the Clatsop Plains dune area, the normal (per acre) applications have cost from $6 to $8 applied. The costs for plantings are based on stock costs of $25 per ton, labor at $1.20 per 6-hour day, and miscellaneous costs such as transportation and supervision. Stock dug from natural hummocks on an area usually will cost at least $50 per ton, if labor is used at the rate cited above. Approximately

16 man-days are required to plant an acre with 18-inch spacing and 40 man-days for the 12-inch spacing. About 58,000 culms weighing 610 pounds are required for a planting, if 18-inch spacing and three culms per hill are used.

Intermediate Step—Seeding Secondary Species in Initial Plantings

European beachgrass, American beachgrass, and American dunegrass are plants primarily adapted to sites where there is an annual sand deposition. When the sand has been partly stabilized, these primary sand-stilling plants frequently lose much of their vigor and do not make a complete cover. Under these conditions, a quantity of dead stalks accumulates in the new growth, and some plants may die. The planting thus may become patchy, with open areas of sand. To insure the development of a more permanent type of cover, it is advisable either to sow seeds of secondary, more permanent, grasses and legumes, or to introduce woody plants by transplanting or seeding. Sandy soils usually are deficient in nitrogen, and the introduction of legumes results in building up the nitrogen and in a stimulation of the grasses.

Seaside lupine, *Lupinus littoralis* Dougl., native to the coastal sand dunes of the north Pacific coast, has proved to be one of the successful legumes for seeding into initial plantings of sand-stilling grass. It is naturally a strong seeder; the seeds germinate readily and the plant usually sets a crop of seed the first season. In places (fig. 18, *A*) this lupine already has developed so rapidly in European beachgrass plantings that it has formed almost solid cover. The effectiveness of seaside lupine as ground cover is somewhat lessened by the fact that it dies down and disappears during the winter, except for the old, dead leaves and stems, which serve as a mulch. The plant is particularly valuable as a soil improver, paving the way for permanent grasses. Collection of the lupine seed by hand is necessary, because of the uneveness in ripening. Pods should be gathered after the seeds have begun to show a mottled color but before the pods dry and open. The pods should be spread on a canvas or sheet in the sun to dry, or they may be dried by slight artificial heat. The seeds shatter out as the pods dry and open. This lupine, though very valuable for seeding into initial grass plantings, will not stand much competition and should be replaced with other legumes as the plant cover becomes more dense.

Purple beach pea, *Lathyrus japonicus* Willd.,* (fig. 18, *B*) will stand somewhat more vegetative competition than the lupine, but as the sod continues to become more compact it usually is supplanted by clovers.

Among the native grasses of the northwest coast that have proved successful for seeding into initial grass plantings are seashore bluegrass, *Poa macrantha* Vasey, and native red fescue, *Festuca rubra* L., (fig. 19). Seashore bluegrass is able to withstand some sand deposition and survive under difficult conditions. It spreads rapidly by seed and by elongated stems that may take root to form new plants. It is well suited to seeding with seaside lupine in initial plantings of European or American beachgrass. Only part of the seashore bluegrass plants bear seed, as some are staminate. In collecting seed, filled heads should be taken. Native red fescue does well in sand that has been

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*This is the plant previously known as *Lathyrus maritimus* Bigel.

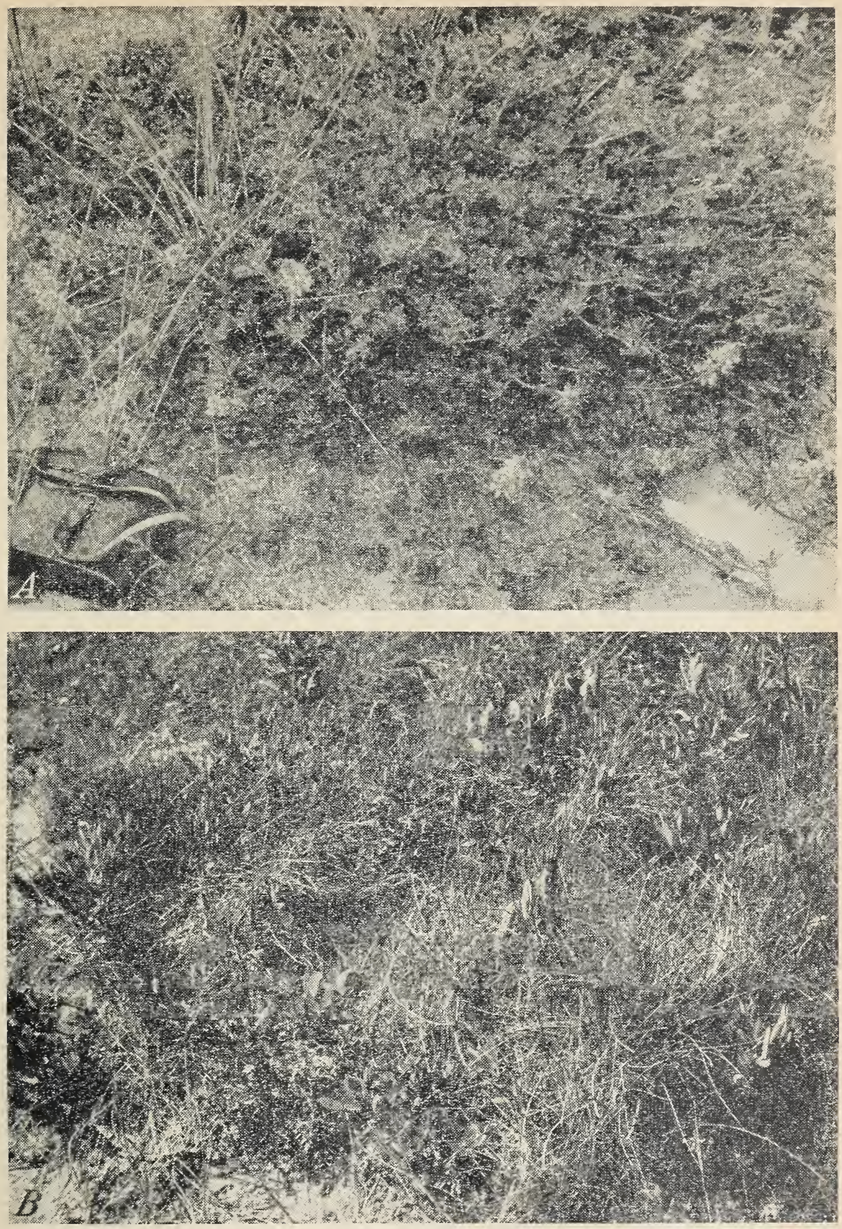

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FIGURE 18.—Native legume species valuable for an intermediate step in dune-control plantings. These species are seeded into initial beachgrass plantings to provide mulch and nitrogen for the more permanent plantings. *A*, Seaside lupine, *Lupinus littoralis* Dougl.; *B*, purple beach pea, *Lathyrus japonicus* Willd.

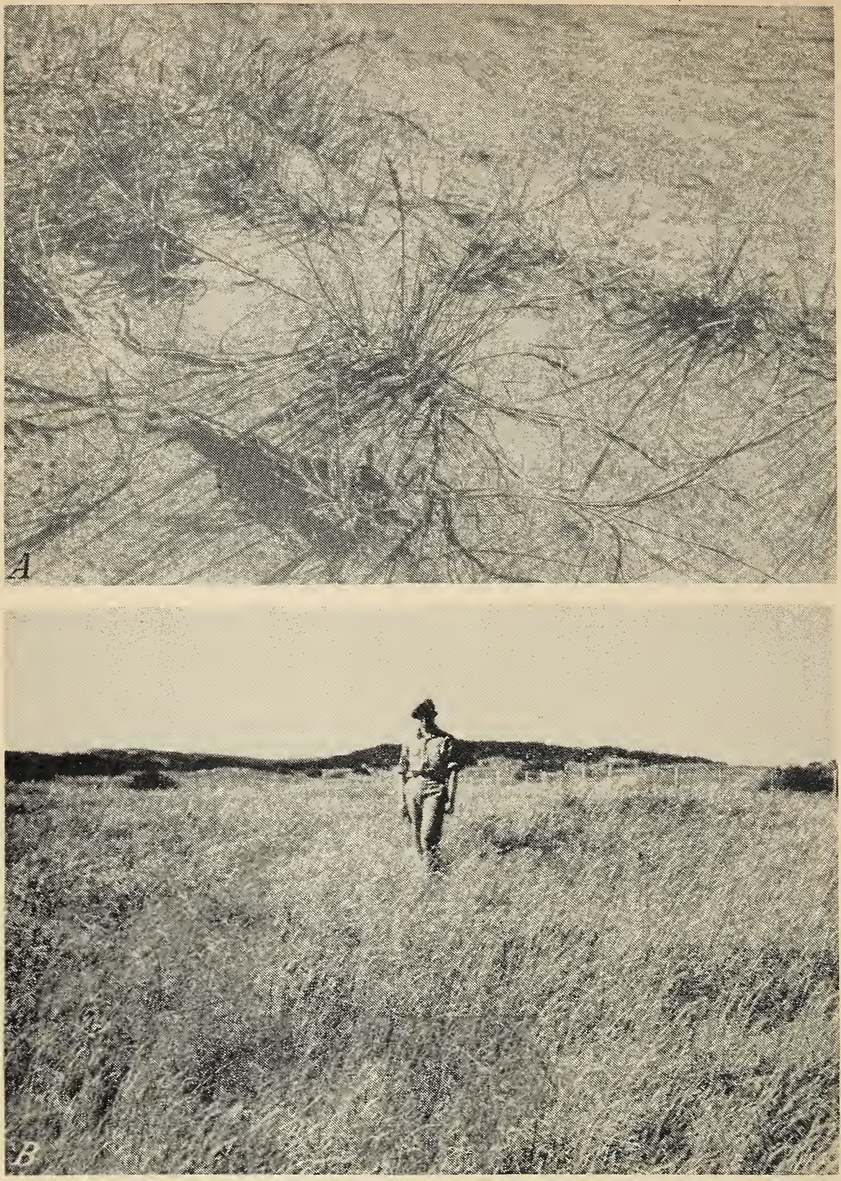

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FIGURE 19.—Native grasses adapted for dune-control seeding in the intermediate and final stages because of their spreading habit of growth and ability to grow under conditions of low fertility: *A*, Seashore bluegrass, *Poa macrantha* Vasey, used in intermediate stages; *B*, native red fescue, *Festuca rubra* L., used in final stages of control.

stilled almost entirely, but it cannot withstand sand deposition. This grass produces a cover over large areas of coastal dunes, especially on the drier sites.

Collecting seed of these native grasses is laborious and expensive. The most satisfactory method, especially on small lots, is to strip the seed heads by hand or to clip with a hand sickle. Where a heavy or nearly pure stand occurs, it is practicable to use a mowing machine or combine harvester, if the area is several acres in extent and smooth enough for operation of machinery. Cleaning after threshing can be done by blowing out the inert material in a breeze or by running the seed through a common seed cleaner.

Of the commercial grasses, sweet vernal, *Anthoxanthum odoratum* L., and velvet grass, *Holcus lanatus* L., are fairly satisfactory, but neither will survive the amount of sand deposition that seashore bluegrass thrives on. Creeping red fescue, *Festuca rubra* L., is one of the more promising grasses commercially available and may replace the native red fescue, especially where the latter is not available. Seeding of annual grasses or cereal grains cannot be recommended.

It is best to defer secondary seedings until after the initial plantings of beachgrasses are 2 years old. Prior to this, there is likely to be an excessive amount of sand movement. Seeding should not be put off after the sand is stilled, as competition of vegetation from the initial planting becomes keen, and the sand dries to a depth greater than the zone used by young grass and legume seedlings. The period when secondary seedings should be made will vary greatly under different conditions. Seedings do best if made fairly thin and allowed to increase in density to what the site will support. The main object is to make the seedings even. Data for computing seeding rates are given in table 3.

TABLE 3.—*Rates for seeding grasses and legumes used in secondary seeding on marine dunes*

Scientific name	Common name	Seeds per pound, average	Average cost per pound, 1936–40	Recommended rate per acre if seeded alone
		Number	*Cents*	*Pounds*
Agrostis spp	Bentgrasses	[1] 8,154,000	60	2
Anthoxanthum odoratum	Sweet vernal grass	[1] 724,800	35	9
Festuca rubra	Chewings fescue	[1] 552,207	40	12
	Native red fescue	[2] 552,500	[3] 60	12
	Creeping red fescue	[1] 543,600	50	11
Lolium multiflorum	Common ryegrass	[1] 226,500	5	25
Poa macrantha	Seashore bluegrass	[2] 166,250	[3] 58	36
Lathyrus japonicus	Purple beach pea	[2] 12,250	[3] 41	45
Lupinus littoralis	Seaside lupine	[2] 76,000	[3] 45	15
Trifolium procumbens	Hop clover	[2] 2,422,000	30	3
Trifolium repens	White Dutch clover	[1] 679,500	75	5
Trifolium involucratum	Cow clover	[2] 346,545	[3] 53	7

[1] Based on Federal Seed Act data.
[2] Based on data obtained by the authors.
[3] Average cost as taken from nursery cost accounts.

Seeding may be done late in the fall or early in the spring. Fall seeding is preferred, as legumes and grasses seeded in the spring often fail to germinate until the next fall, because of their hard seed and the lack of moisture; thus the chances of success are lessened. It is highly desirable, in any case, to drill all seeds in order to cover them and to insure more uniform distribution (fig. 20). Irregular, rough areas usually must be broadcast-seeded, owing to the likelihood of machinery breakage in seeding these sites. When seed is broadcast, mulching by clipping existing vegetation or by scattering of straw or similar material greatly increases the chances for a successful, even stand.

On smooth areas a 6-foot drill drawn by a track-type tractor or wheel tractor equipped with balloon tires has been found satisfactory when the sand is wet and firm. The drill should be set as shallow as possible; this usually places the seed approximately 2 inches deep.

All legume seeds should be inoculated before being seeded.

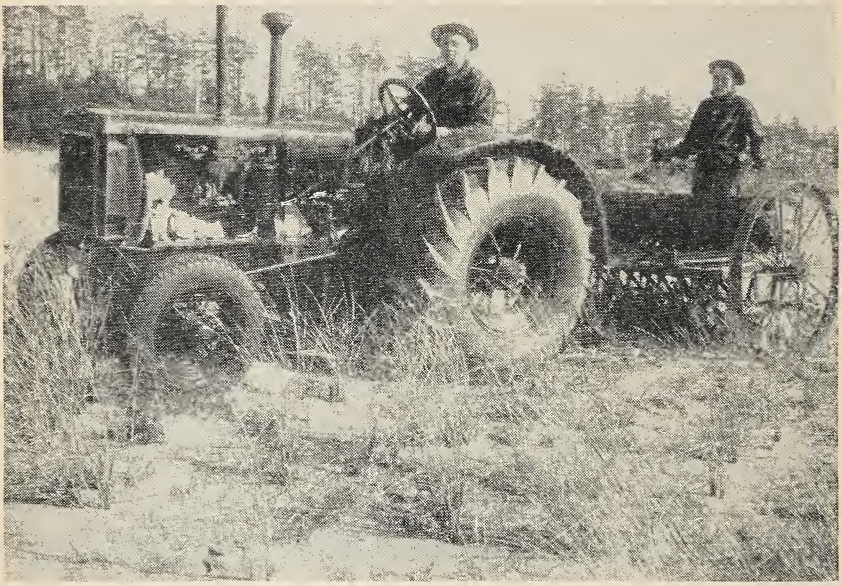
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FIGURE 20.—Seedings of secondary legumes and grasses usually are made in 2-year-old beachgrass stands. By that time there is little sand movement, and drilled seed produces satisfactory stands.

The following mixtures of grasses and legumes have given satisfactory results for secondary and permanent seeding on the Clatsop Plains dune area. The rates of seeding are based on data in table 3.

1. Mixture of grasses and legumes native to the Northwest coast for seeding in drier sites on dunes:

	Pounds per acre
Seaside lupine	5
Seashore bluegrass	12
Beach pea	15
Native red fescue	4

The first two species in this mixture may be seeded together in secondary plantings, followed after a year's interval by the last two species for a more permanent cover.

2. Mixture for secondary seeding on sites subjected to prolonged winter submergence:

	Pounds per acre
Seaside or Astoria bentgrass	2
White clover or cow clover	3
Common ryegrass	5–10

3. Mixture of grasses and legumes commonly available through commercial channels suitable for seeding in drier dune sites:

	Pounds per acre
Highland bent	2
Creeping red fescue	3
Sweet vernal	5
Hop clover	2

Cost of Secondary Seedings.—The cost of making seedings for the intermediate step of control varies so widely that only general estimates can be given. The greatest variable is the cost of collecting seed from the native vegetation. Except for the native red fescue, the stands are scattered, and seed must be collected by hand. The yield of seed varies greatly from year to year depending on climatic conditions and insect infestation. Average values for seed are shown in table 3. By applying these values to the recommended mixtures, an estimate of cost can be made. In practice, the cost of mixture #1 has varied from $7.50 per acre to $17.75 per acre. This mixture has been used for most of the work and has given satisfactory results.

The cost of seeding has varied with site conditions, density of original sand-stilling grasses, and other factors, but has averaged $3 per acre. If a 6-foot grain drill is used, 16 man-hours and 8 tractor-hours are required for seeding 6 acres. The tractor and operator are charged at the rate of $1.50 an hour, the drill at the rate of 25 cents an hour, and a helper at 50 cents.

PERMANENT HERBACEOUS STAGE OF STABILIZATION

Where the desired land use of dune areas requires a herbaceous-sod cover rather than an eventual forest cover, the initial beachgrass plantings are followed by the seeding of secondary grasses and legumes, such as seaside lupine and seashore bluegrass. A second seeding operation establishes the beach pea and native red fescue. As these species are highly palatable to livestock, the future security of this cover depends upon protection. Under protection, on the Northwest coast, the fescue will persist indefinitely over the drier sites. The wetter sites are eventually dominated by bentgrasses. Commonly associated with the fescue on drier sites is hop clover, *Trifolium procumbens* L., while on the wetter areas native white clover, *Trifolium repens* L., and cow clover, *Trifolium involucratum* Ortega, are the common persistent legumes. These persistent grasses and legumes may follow voluntarily close upon the secondary seedings. Where grazing or other use constitutes a definite hazard, however, it has been found advisable to introduce these species by seeding when all sand movement is stopped by the secondary plants.

SECONDARY AND FINAL CONTROL STAGE WITH WOODY SPECIES

There are sites on dune areas where woody plants are needed to obtain effective control. Shrubs and trees should be planted on sand areas only after initial stabilization of the sand has been accomplished. Sites of rough topography created by eroded sand blow-outs, stream banks, and areas vital because of the protection they give to adjacent lands can be treated to advantage with shrubs and trees. The proper eventual land use of the area under consideration is a factor that determines whether woody species are to be used if they are adapted.

In the Clatsop Plains dune area, rough terrain is being planted to woody species for a permanent cover. Gaps and pockets in the dune topography tend to intensify the scouring action of the wind. In order to eliminate these irregularities and restore the smooth, regular, natural, and mature contours, woody plantings have been made, as illustrated in figure 21. After beachgrass has stabilized the sand, pines and Scotch broom are planted. The pine is kept toward the inside, where the greatest height is needed. Broom will persist on the outside, where it is not heavily shaded. The broom, being a legume, builds up the nitrogen while acting as a physical protection from wind for the young pines. This type of planting reconstructs the destroyed topographic forms and alleviates the tendency of these wind gaps to scour and increase in size. As the long dunes themselves tend to divert the surface winds and cause them to move parallel to the dune ridges, woody plantings in gaps and depressions have a tendency to conform to the natural dune contours. Woody plantings are useful to add height to stabilized dunes somewhat distant from the beach, and so to give windbreak protection to lands on the leeward.

As with the grasses and legumes, the important woody species are native or naturalized and are adapted to sandy soil and severe winds. To date the shrubs Scotch broom, *Cytisus scoparius* (L.) Link, Hooker's willow, *Salix hookeriana* Barratt, and Nootka rose, *Rosa Nutkana* Prese., have been used to a great extent. Shore pine, *Pinus contorta* Loud., is the only native tree species used extensively in dune-control plantings. The mature forests that develop naturally over most of the North Pacific coastal dune areas consist of Sitka spruce, *Picea sitchensis* (Bong.) Carr., and western hemlock, *Tsuga heterophylla* (Raf.) Sarg. These species are not used in the dune-control plantings because the sites are too immature to allow their successful establishment and subsequent growth. They will, however, seed naturally into adapted sites when conditions become favorable. In addition to the native or naturalized species of the Pacific coast that are used, there are several introduced species that are adapted. These are cluster pine, *Pinus pinaster* Ait., Scotch pine, *P. sylvestris* L., Table Mountain pine, *P. pungens* Lamb., Austrian pine, *P. nigra* Arnold, and black alder, *Alnus glutinosa* (L.) Gaertn.

Scotch broom and tree lupine, *Lupinus arboreus* Sims. (fig. 22), are regarded as secondary species. Plantings usually are made before establishing permanent trees, as these two shrubs are adapted generally to sand-dune control under the temperate climate of the Pacific coast. These shrubs are especially valuable in the dune-control program because they are leguminous, grow rapidly, give excellent ground

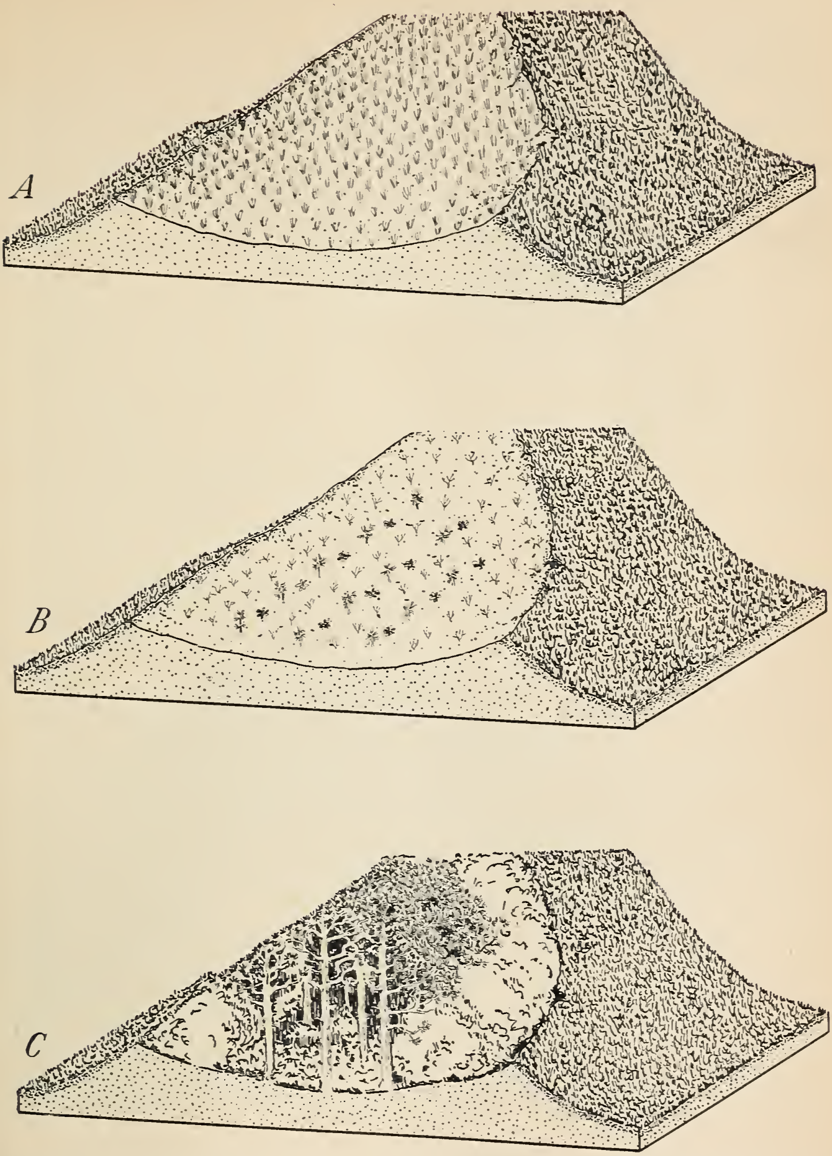

FIGURE 21.—The treatment of a gap in the dune ridge caused by trailing of livestock. *A*, The gap is planted to beachgrass partially to stabilize the sand. *B*, Pines have been introduced, together with Scotch broom as a nurse crop (grass is omitted in drawing). *C*, The mature planting tends to conform to the contours of the surrounding topography because of the wind.

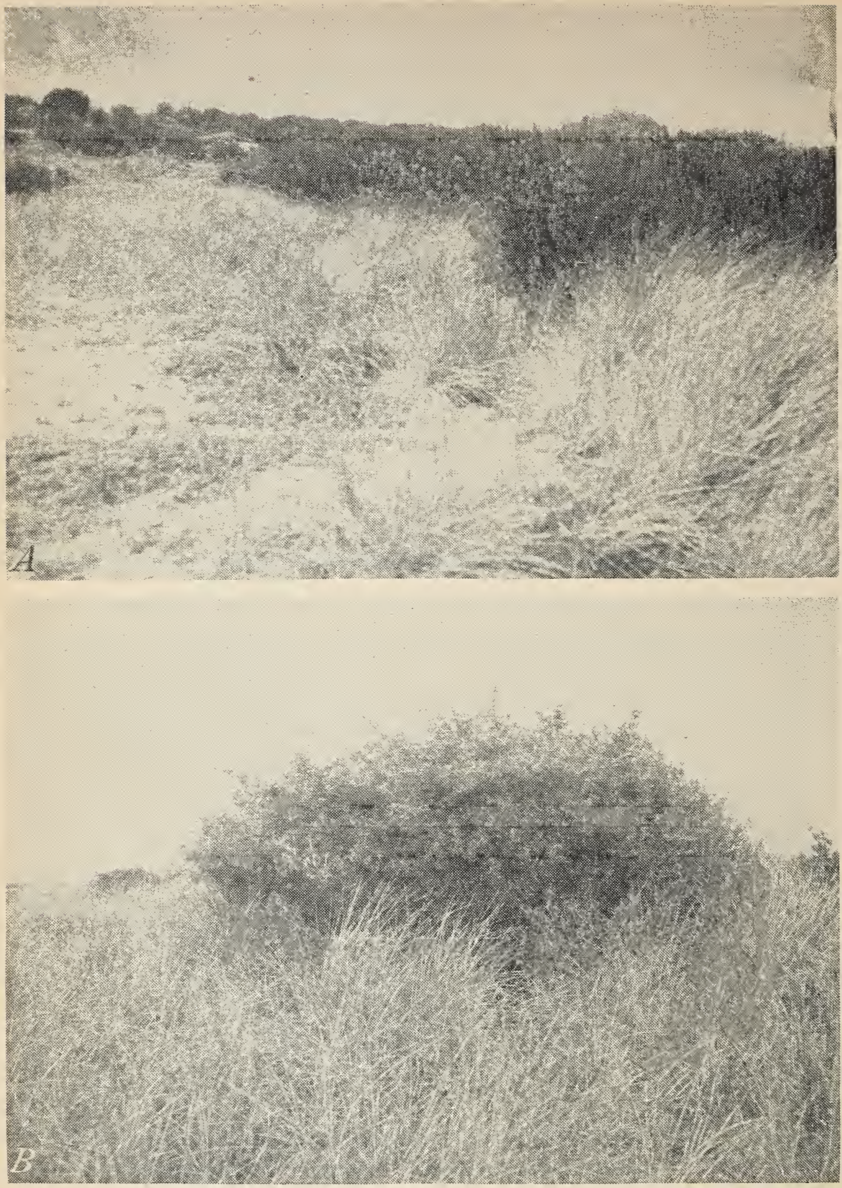

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FIGURE 22.—Leguminous shrubs used in the secondary stage of dune control with woody species. *A*, Scotch broom, *Cytisus scoparius* (L.) Link, 3 years old, planted in an established stand of European beachgrass; *B*, tree lupine, *Lupinus arboreus* Sims, 3 years old, from seed broadcast in an established stand of European beachgrass.

cover, provide an abundant litter that aids in improving the fertility of the dune sands, and are not readily browsed by livestock.

There are site conditions for which the use of Scotch broom and tree lupine is not recommended. The plants cannot stand the severity of conditions existing on the foredune, are intolerant of shade, and do not grow with maximum vigor on very wet or heavily sodded ground. These species are useful for plantings on road cuts and fills, blow-outs, upper parts of lake shores, and stream banks that are sloughing, and as a nurse crop for the slower growing permanent woody plants.

Scotch broom is best when planted as 1-year-old nursery-grown stock, because survival is higher and cover is produced more rapidly than where seedings are made. The tops of the stock are cut back in the nursery to approximately 12 inches. This clipping promotes the growth of side branches and general bushiness of the plants so essential for maximum protection of the soil surface and of the interplanted permanent species. The roots are trimmed to approximately 10 inches in length. This root trimming frees the plant of all long stringy roots and broken ends and makes for better planting. Stock must be at least ⅛ inch in diameter 1 inch above the root collar and preferably ¼ inch. Larger stock than this is not desirable. The desired type of stock is very easily and economically produced.

Tree lupine, however, does not transplant well, and direct seeding is recommended. This method of establishment is successful, as the seeds are large and seedling growth is rapid. It is essential to follow certain cultural techniques very closely, however, or failure of the crop is to be expected. Lupine, being a legume, requires inoculation, which must be especially prepared for the tree lupine. Seeding must be done immediately after inoculation, care being taken to see that seed does not lie in sunlight. The seeding is accomplished by means of a long-handled dibble or hand corn planter modified to handle this size of seed. It is desirable to plant in hills rather than broadcast the seed or drill. Seed must be sown approximately 3 inches deep in order to remain in moist sand at all times.

Plantings of these secondary woody species may be made in initial plantings of European beachgrass at about the same stage in the control program as the secondary grass and legume seedings. Scotch broom or tree lupine used as a nurse crop should be spaced about 4 by 4 feet. Pine and broadleaf trees may be planted at the same time as the Scotch broom, if sufficient beachgrass cover is present to prevent any appreciable sand movement, or they may be planted 1 or 2 years later, after the grass has developed sufficiently to afford protection. Such plantings are shown in figure 23. The spacing of pines and other permanent species is usually from 4 by 4 feet to 6 by 6 feet, depending on the site condition and the species used.

Secondary shrubs, such as Hooker's willow and Nootka rose and the more permanent red alder and Oregon crabapple, have limited use in a dune-control program as they are deciduous in habit and hence do not afford much winter protection. Hooker's willow, alder, and crabapple prefer the moist or wet sites adjacent to swamps or lakes. The Nootka rose grows very well on the drier sites. The rose and crabapple are valuable wildlife food, whereas the value of the willow is primarily for sand binding and wildlife cover.

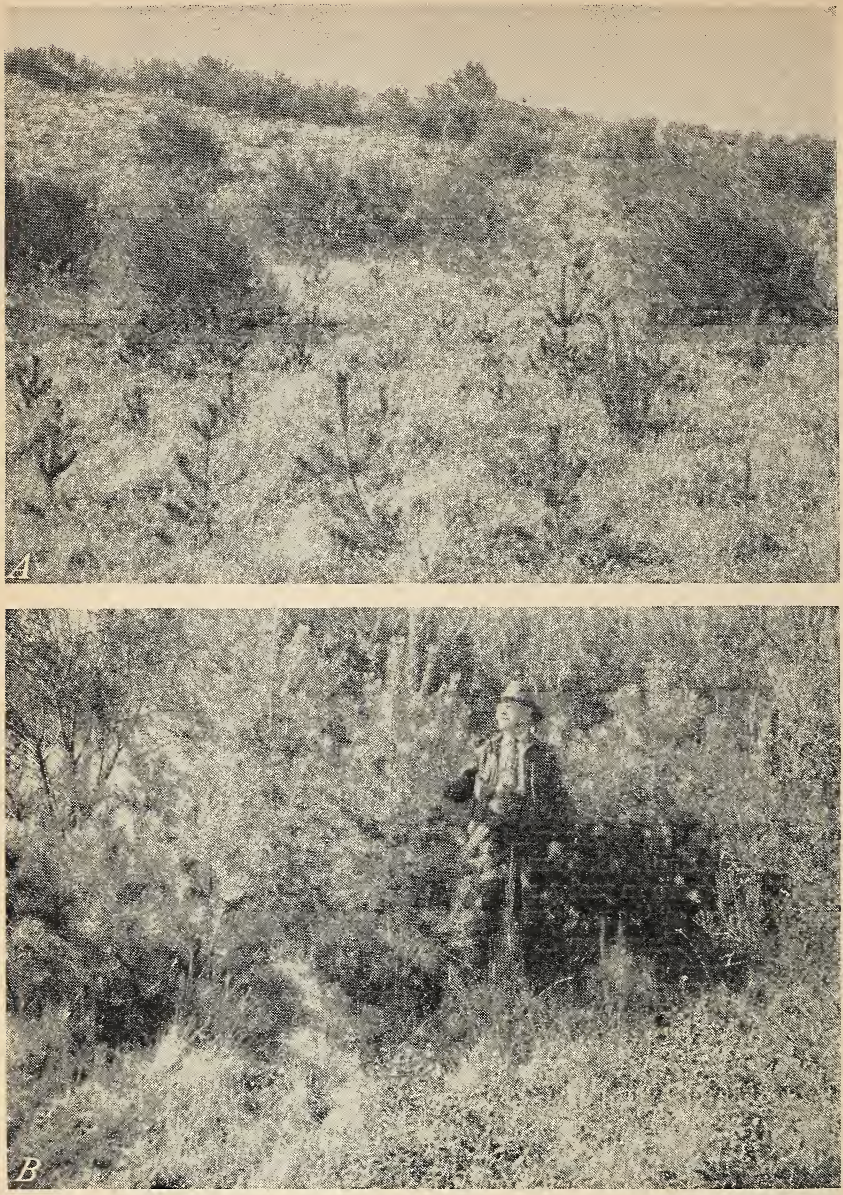

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FIGURE 23.—Coniferous trees for final stage of dune control. *A*, Three-year-old shore pine, *Pinus contorta* Loud., planted in a thin stand of Scotch broom. *B*, Five-year-old planting of Scotch pine, *Pinus sylvestris* L., planted with a nurse crop of Scotch broom.

Either with, but preferably after, plantings of the secondary woody species, the permanent woody species, such as pines, crabapple, and alders can be made. Growth on most permanent species is slight for the first 2 years after planting, but after that period, it is often as much as 2 feet annually.

In areas where the topography is rough, where the land is subject to future disturbances of one kind or another, or the future land use is to be for recreational or wildlife purposes, it may be desirable to supplement permanent woody species with plantings of understory plants that are evergreen and tolerant of shade (fig. 24). These plantings should not be made until some shade and overstory protection is afforded. On the north Pacific coast two species, evergreen huckleberry, *Vaccinium ovatum* Pursh, and salal, *Gaultheria shallon* Pursh, serve to fill the need for such a protective covering on the forest floor. These plants form a very dense evergreen cover full of fruit valuable as wildlife or human food. The propagation of understory species is not a simple undertaking. Their use will, therefore, usually be limited by the small available supply of planting stock. There are other species available for understory planting: but most of these are not evergreen, thus limiting their effectiveness. Spacing of these species is usually 4 to 6 feet each way, although closer spacing ordinarily reduces maintenance costs encountered where wide spacings are used.

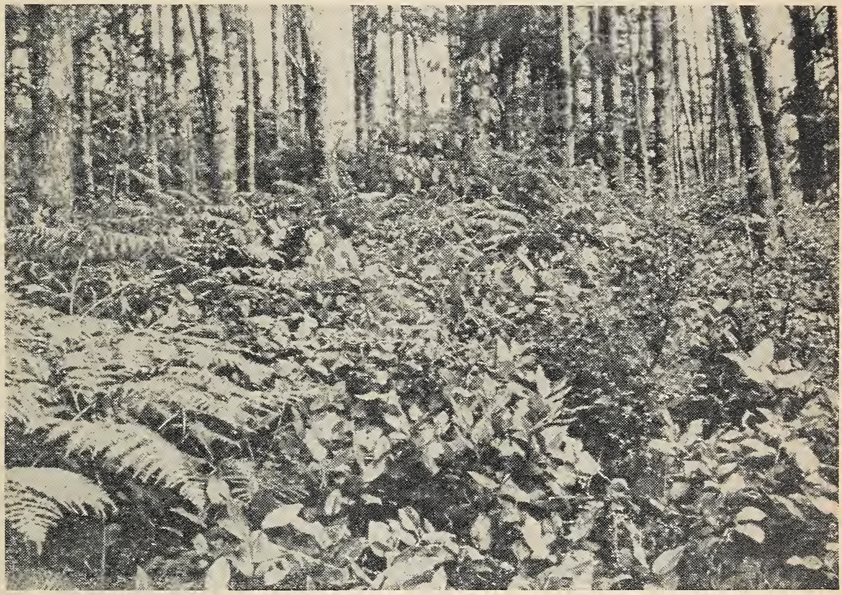
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FIGURE 24.—An understory of salal, evergreen huckleberry, and fern in a stand of shore pine on the Clatsop Plains dune area gives complete protection to the forest floor and provides food and cover for wildlife and berries for human food.

On the dunes of the north Pacific coast plantings of woody species in late fall and winter make more growth and show higher survival than spring plantings. This is due largely to the fact that fall and winter plantings have a greater length of time for establishment before dry weather.

Stock used for all woody plantings should be nursery-grown, as wildings dug or pulled from native stands seldom give good survival or growth. In the case of nursery-grown stock, it is preferable that it be grown from seed from a local source. Only grade 1 stock should be used, as smaller and less strongly rooted plants give poor survival and growth. Deciduous stock should be at least 12 inches in height. If it is taller than this, the tops usually are clipped back to the minimum height in an effort to promote a bushy form so desirable in dune plantings. The minimum diameter of deciduous stock acceptable for dune planting is ⅛ inch in diameter 1 inch above the root collar; however, diameters approximating ¼ inch are preferred, because the larger plants will stand more severe site conditions. The root system should be well branched and have many fibrous feeder roots. Broken roots should be trimmed off and all tips clipped back to approximately 12 inches to facilitate planting. The age of deciduous stock will vary from 1- to 2-year-old seedlings, depending on the species and conditions under which they are produced. It is essential that the stock meets the minimum specifications.

Coniferous planting stock usually can be smaller than deciduous stock. The minimum height desired for the pines is 6 inches, and the maximum is 12 inches. Stock from 8 to 10 inches is the most convenient size for planting. Stock larger than the maximum height may be clipped to the desired height without detrimental effects if it meets all other specifications. Minimum diameter at the root collar is ⅛ inch. Maximum diameter seldom should be more than ⅜ inch, as such stock generally becomes completely oversize and hard to plant. Root-system specifications are essentially the same as for deciduous stock. All stock should be dormant and free from disease and insect pests.

Stock, if received from a distant nursery, usually comes in some type of bale. In some instances, stock is so well packed that it can be kept in these bales for a week, if the weather is not too warm and the bales are kept in the shade. If this practice is followed, it is imperative that the stock be watched closely to see that it does not dry out or heat. It is advisable under most conditions to remove the stock from the bale and place it in heel-in beds in a shady place where it can be kept moist. Care should be taken when heeling-in stock to see that soil is packed firmly about the roots and that the roots are straight. Soil should not be placed higher on the stock than the original ground line.

Crews for planting tree stock are organized essentially the same as for initial grass plantings. The planting tool used for most stock is the tile or drain spade used for grass planting. With some of the larger rooted stock, a long-handled, round-point No. 2 shovel is used. Where it is possible to use the tile spade, the planting is speeded up, and costs are lowered.

It is essential, when planting tree stock, to firm the soil about the roots in such a way as to avoid air pockets. Woody plants, other than willow, should be set to the same depth in the field as they grew in the nursery; this is especially true for coniferous species, because they are intolerant of being buried to any appreciable depth. Willows may be planted considerably deeper than they grew in the nursery. The roots of woody stock must be kept moist and out of the wind and sun while they are being handled. When planting stock is carried in the field it should be kept moist in a pail, should be wrapped in wet burlap, or placed in specially made carrying trays. It is best to carry only a small amount of stock at a time, leaving the remainder heeled in.[4]

The average number of trees planted per man in a 6-hour day on the sand dunes is approximately 600. This number will vary greatly with the kind and the condition of the planting stock. The cost of planting an acre with shrubs or trees depends on many factors, including price of stock, spacing or density of planting, number of species being planted, and age and condition of planting stock.

As was the case with seedings of secondary and permanent herbaceous species, only general estimates of cost can be given. Average values per thousand for nursery-produced stock are: Scotch broom, \$3.50; deciduous shrubs, \$4; deciduous trees, \$5; conifers, \$7; understory shrubs, \$30. At these values and with a planting rate of 100 trees per man-hour, a mixture of Scotch broom and pine planted 6 feet by 6 feet, staggered, would cost approximately \$30 per acre. In this case the cost of the stock and of the labor and supervision are divided about equally. Dense plantings of deciduous shrubs for the stabilization of blow-outs and other critical areas may sometimes cost as much as \$200 per acre, but such plantings are usually confined to relatively small but critical areas. For such plantings the cost of the stock may be only one-third the total cost.

PLANTS NOT RECOMMENDED

Some native plants of the Northwest commonly present in abundance on coastal dunes are not satisfactory for use in stabilization work. Because of their growth characteristics, they may cause undesirable hummocking, or they may, because of insufficient winter ground cover, permit severe wind scour. Species that provide insufficient ground cover in winter because the tops die back or are inadequate include: Big-headed sedge, *Carex macrocephala* Willd., seashore tansy, *Tanacetum douglasii* DC., and baltic rush, *Juncus balticus* Willd. If present, these plants even make it difficult to establish more desirable species. Species that develop taproots and tend to cause hummocking include sand verdena, *Abronia latifolia* Esch., and sandburs *Franseria chamissonis* Less. and *F. bipinnatifida* Nutt., Glehnia, *Glehnia leiocarpa* Math., and dune morning glory, *Convolvulus soldanella* L.

NEED FOR MAINTENANCE AND PROPER LAND USE

Actively moving dunes have been caused, in most instances, through the intervention of man. It now becomes the duty of man to see that the protective vegetal cover is maintained and that the sand movement is controlled on these dunes. There is no justification for costly plantings unless the permanent cover of sod or forest is to be maintained. This means protection from fire, from excessive grazing, and from all other uses that tend to destroy the vegetation. Initial plantings of beachgrass cannot be left entirely forgotten; they must be interseeded with secondary grasses and legumes, or planted to woody species, and provisions made eventually to obtain a firm sod or dense woody cover. Such cover must be maintained by proper land use and management.

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[4] Complete directions for planting shrubs and trees can be obtained by writing to the State experiment station or consulting the following:
TILLOTSON, C. R. GROWING AND PLANTING HARDWOOD SEEDLINGS ON THE FARM. U. S. Dept. Agr. Farmers' Bul. 1123, 28 pp., illus. 1932. (Revised.)

More important than reclamation of the dune lands is protection of cultivated lands, pastures, and other types of land, underlain by sand, that are potential active dune areas. It is much easier to utilize these lands moderately and with judgment than to reclaim them after the sand has begun to blow.

SUMMARY

Areas of unstable sandy soils are widespread throughout the United States and on the Pacific coast occur locally from Baja California to southern Alaska.

Coastal dunes, if uncontrolled, are present and potential threats to agricultural and timber lands, municipal, resort, and military properties, and cause shoaling and blocking of navigable waterways.

Localized control work in the Pacific Northwest culminated in the extensive control project in the Clatsop Plains dune area in Clatsop County, Oreg., undertaken in 1935 by the Soil Conservation Service, working with the Civilian Conservation Corps. Supplementing this control work, observations and studies have given much information regarding the natural forces involved and the most effective methods for their control (table 4).

The prevailing summer wind on the Clatsop Plains dune area is north to northwesterly, and the average velocity is approximately 13 miles per hour, with maximum velocities up to 40 miles per hour. In winter the prevailing direction is southerly, and the average velocity is 16 miles per hour, with occasional storm winds that may reach velocities of more than 55 miles per hour and move large quantities of sand inland.

Under normal conditions, the native vegetation stops most of the sand in the zone behind the storm tide line, where a barrier dune builds up parallel to the beach. Stabilized dunes inland from the foredune have become active by destruction of the vegetal cover through fire, grazing, trailing of livestock, construction, and other causes. The building of jetties at the mouth of rivers has caused abnormally rapid sand deposition, resulting in the development of sand flats that form oceanward more rapidly than the vegetation could occupy the area. These sand flats have been the point of origin of dunes that tend to move inland. Agricultural use of dune soil is limited largely to those areas having a surface layer of high humus content.

Mechanical controls, such as brush mats and sand fences are temporary only. Oil, rock, and clay are of limited value for holding sand. The most effective means of controlling coastal dunes is by the establishment of a permanent vegetal cover. Grasses and legumes provide adequate ground cover, except where it is desired to discourage trespass or where taller vegetation is required to give windbreak protection and to smooth out topographic irregularities. There woody vegetation is required.

Table 4.—*Summary of control methods and proper land use on various types of dune-control areas*

[North Pacific coast]

Type of control problem	Cause of blowing sand	Control measures	Protection and land use
(1) Foredune	Normal deposition from beach.	Establish plantings of beachgrasses or double line of picket fences supplemented by beachgrass plantings.	Maintain uniform beachgrass cover. Avoid irregular topography, Protect from grazing, trailing, and excavation.
(2) Unvegetated spit or sand flat.	Accelerated sand deposition caused by jetty construction, changing ocean currents, or severe erosion upstream.	Maintain foredune for protection on windward side. Plant sand-stilling grasses. Two years later drill in legume and permanent grass seed.	Protect from fire and grazing. Maintain plantings and seedings.
(3) Irregular area near beach.	Overgrazing; fire; trailing by livestock or by people; excavation.	Plant sand-stilling grass. At end of second year drill in legume and permanent grass seed. Tree and shrub plantings may be made, especially on the more irregular areas, for added permanent cover.	Protect from fire and grazing. Limit use to recreational activities and wildlife. Maintain an adequate vegetal cover.
(4) Small isolated blow-out back from beach.	Overgrazing; trailing; excavation; cultivation; fire.	Remove cause. Plant and fertilize sand-stilling grasses. After 2 years, drill seed of secondary or permanent grasses and legumes. If area is small, it may be possible to resort to the use of sod for cover.	Control or remove grazing. On cropland use shallow tillage and cover crops. If humus layer is destroyed, do not graze or crop.
(5) Large blow-out surrounded by timber.	Fire or logging	Plant sand-stilling grasses. After 2 years drill in legume and grass seed. Allow reproduction to come in or plant to trees and shrubs.	Protect from fire and grazing. Do not clear out timber. Limit use to recreational activities and wildlife. Use for timber production only with stringent control.
(6) Road, trail, or railroad; livestock trails.	Construction or natural trailing by livestock or people with resultant destruction of vegetal cover and of topsoil layer.	Protect bottom from further cutting by providing erosion-resisting surfaces such as oil, plank, rock, clay, and concrete. Plant sand-stilling grasses and later establish permanent herbaceous or woody vegetation on sides.	Keep all sand covered by vegetation or by erosion-resisting surfacing material.

Three principal steps are required to establish a permanent vegetal cover on coastal dunes. The initial step consists in the transplanting of beach and dune grasses to arrest sand movement and may include building of a foredune. Then, intermediate seedings or plantings of leguminous species are necessary as soon as the beachgrasses have stilled the moving sand. Permanent grasses and legumes or shrubs and trees are established, finally, by seeding or planting them with the intermediate species or after these species have become established.

In establishing initial grass plantings, the order of planting should be from the windward toward the leeward side. Plantings should be uniform, without unprotected gaps or strips. On the north Pacific coast the wet winter season, extending from November 1 to May 15, is the average optimum planting time. Areas subject to winter submergence should be planted in the spring as the water level recedes.

Successful sand-stilling grasses for initial control must have coarse culms able to withstand sand blasting, be able to recover through a foot or more of sand deposition, make rapid stem increase, possess an extensive root system, and preferably be capable of extending horizontally for considerable distance by vegetative reproduction. Grass planting stock should be dug during cool weather when the plants are dormant or nearly so. It should consist of individual culms with one or two underground nodes. Culms should be cleaned and the leaf tips trimmed back. Properly heeled-in planting stock may be stored for 2 weeks or more during cool, moist weather. Planting crews are most effectively organized in groups of two men, one opening a hole and the other placing stock and firming the sand. On average sites three culms per hill, with a spacing of 18 inches between hills, is satisfactory, but these rates should be adjusted as necessary. Directions are given indicating proper planting on a wide variety of sites.

European beachgrass is the principal grass that has been used on the north Pacific coast for initial plantings. American beachgrass is being used as rapidly as it can be made available. American dunegrass has been used to a lesser extent.

Nitrogen-bearing fertilizers give definite growth impetus and are of value particularly when the time element is important. Application should involve a minimum of 20 pounds of nitrogen per acre.

With 18-inch spacing, approximately 16 man-days are required to plant an acre. This involves about 58,000 grass culms weighing 610 pounds.

Seaside lupine, seeded a year or two after the initial planting is a valuable adjunct to the beachgrass because it supplies litter to the surface and nitrogen to the sand. Other native grasses and legumes of value for secondary seeding include purple beach pea, seashore bluegrass, and native red fescue. Grasses commercially available and suitable for seeding into beachgrass plantings include sweet vernal, velvetgrass, and creeping red fescue. Fall seeding by drilling gives the best results.

The most important shrubs have been Scotch broom, tree lupine, Hooker's willow, and Nootka rose. Adapted trees include the native shore pine, Oregon crabapple and red alder, and the introduced cluster pine, Scotch pine, Table Mountain pine, Austrian pine, and black alder. Scotch broom and tree lupine are particularly valuable as secondary woody species and are useful as nurse-crop plantings for more permanent woody plants. Scotch broom is best planted as 1-year-old nursery-grown stock, but the lupine is more successfully seeded in its permanent location. Plantings of these secondary woody species may be made in beachgrass plantings at about the same stage in the control program as secondary grasses and herbaceous legumes. Other deciduous shrubs, such as Oregon crabapple and Hooker's willow, have limited value and give little winter cover.

Permanent woody species may be planted at the same time as the secondary woody species, but it is preferable to plant them a year later. Understory woody plants should not be introduced until suitable shade and overstory protection are provided.

On dune areas in the north Pacific coast section, late fall is the optimum planting period for woody species. High-grade nursery-grown stock is most successful, and proper care in shipping, storage, and planting should be observed. The average number of trees planted per man-day on the Clatsop Plains sand dunes is approximately 600.

Proper land use and careful maintenance of all plantings are essential to permanent control of coastal dune areas.

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